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The Stroop Task and Attention Deficits in Schizophrenia: A Critical Evaluation of Card and Single-Trial Stroop Methodologies

William M. Perlstein, Cameron S. Carter, Deanna M. Barch, and James W. Baird
University of Pittsburgh School of Medicine, Western Psychiatric Institute and Clinic

The Stroop task, considered by many to be a paradigmatic measure of selective attention, has often been employed to investigate attention deficits in schizophrenia. Card and single-trial versions of this task have yielded different results. In this study both card and single-trial versions were administered to healthy controls (n = 24) and patients with schizophrenia (n = 55). No differences in reaction time (RT) interference were found on either version. On the single-trial version, patients showed greater RT facilitation and error rate interference, evidence for a deficit in selective attention. Methodologic and analytic issues that account for the mixed results from earlier card Stroop studies are addressed. It is concluded that single-trial versions provide greater sensitivity to selective attention pathology in schizophrenia.

The Stroop task (Stroop, 1935) has been considered a paradigmatic measure of selective attention in neuropsychology and cognitive psychology for more than 60 years. The Stroop task requires participants to attend to a single dimension of a stimulus while simultaneously ignoring other, task-irrelevant dimensions. Variants of the original task employed by Stroop (Experiment 2) are still commonly used in neuropsychological studies. The most frequently used version of this task comprises lists of word and color-patch stimuli displayed on cards, with each of three conditions represented on a different card: (a) word reading—in which participants read words printed in black ink, (b) color naming—in which participants name the color of patches or rows of *X*s printed in different colors, and (c) color–word naming (i.e., conflict condition)—in which participants name the color of words printed in incongruent colors (e.g., the word *RED* printed in blue). The time taken to complete each card, or the number of items completed within a prespecified time limit, serve as overall measures of task performance. The Stroop task has led to one of the most reliable findings in psychology: When naming the ink color of color-incongruent words, participants have difficulty suppressing the intrusive effects of the words. This finding is reflected in slower color-naming times for color-incongruent words relative to "neutral," non-conflict color stimuli. This effect, known as Stroop interference, is thought to result from the prepotent tendency to read words (Macleod, 1991) competing with the participant's color naming response.

Attentional impairments have been noted in schizophrenia since its earliest descriptions (Kraeplin, 1919/1971) and are considered by many to be a core manifestation of the disease process (e.g., Bleuler, 1911/1950; Braff, 1993; Callaway & Naghdi, 1982). Thus, it is not surprising that the Stroop task has been used to investigate attentional pathology in this disorder. Schizophrenia researchers have used two general versions of the task, which differ primarily in the mode of stimulus presentation: card and single-trial versions. Neuropsychological studies of patients with schizophrenia have typically used card versions of the Stroop task. A large number of studies have been conducted, and Table 1 lists the studies cited in this article. Studies cited in Table 1 include only those that provide sufficient detail to address relevant factors, such as derivation of an interference score, as discussed later. A number of other neuropsychological studies of schizophrenia have employed the card Stroop. However, these other studies have not been included in Table 1 because they either collapsed the results of Stroop task performance into composite scores that include scores from other tests putatively reflecting "frontal" or "executive" functioning (e.g., Cannon et al., 1994; Saykin et al., 1991, 1994) or did not include a control group (e.g., Liddle & Morris, 1991; Nopoulos, Flashman, Flaum, Arndt, & Andreasen, 1994).

Findings from card Stroop studies of patients with schizophrenia have consistently shown that patients exhibit overall slowing of reaction times (RTs) estimated across an entire card or complete fewer items across all conditions (i.e., a generalized deficit). More importantly, these studies have also shown that patients exhibit greater slowing of estimated RTs in the conflict condition compared to healthy and

William M. Perlstein, Cameron S. Carter, Deanna M. Barch, and James W. Baird, Department of Psychiatry, University of Pittsburgh School of Medicine, Western Psychiatric Institute and Clinic.

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Correspondence concerning this article should be addressed to Cameron S. Carter, University of Pittsburgh School of Medicine, Western Psychiatric Institute and Clinic, 3811 O'Hara Street, Pittsburgh, Pennsylvania 15213. Electronic mail may be sent to cscarter+@pitt.edu.

Table 1
Card Stroop Studies of Schizophrenia

Study	Participants	Tasks	Dependent measure	Analysis method	Results
Wapner & Krus (1960)	24 schizophrenics (medication status uncertain); 24 healthy controls	WR, CN, CWN	Mean RT for completed items (within time required to complete each card)	Group comparisons for each condition separately	Patients show significantly longer RTs in all three conditions
Golden (1976)	35 schizophrenics (medication status uncertain); 37 healthy controls	WR, CN, CWN	Number of items completed (within 45-s time limit)	Group comparisons for each condition separately	Patients complete significantly fewer items in all three conditions
Abramczyk et al. (1983)	30 schizophrenics (medication status uncertain); 35 inpatient psychiatric controls (mixed)	WR, CN, CWN, "letter reading"	Mean RT for completed items (within time required to complete each card)	ANOVA on CN, CWN (also used a "partial control" for differences in letter-reading speed)	Patients show significantly increased RT interference (measured by CN − CWN difference score) when not controlling for general reading speed
Wysocki & Sweet (1985)	25 schizophrenics (medication status uncertain); 25 nonpsychiatric medical controls	WR, CN, CWN	Age-corrected raw score for number of items completed (within 45-s time limit)	Group comparisons for each condition separately	Patients complete significantly fewer items in all three conditions
Killian et al. (1984)	34 schizophrenics (unmedicated then medicated); 26 healthy controls	WR, CN, CWN	WR − CN difference score (within time required to complete each card) Number of errors on CWN card	Group comparisons for each condition separately	Patients show significantly greater "interference" (measured by the WR − CN difference score) and more errors in CWN condition
Everett et al. (1989)	22 schizophrenics (medication status uncertain); 22 healthy controls	WR, CN, CWN	Mean RT for completed items (within 45-s time limit)	Group comparisons for each condition separately	Patients show significantly longer estimated RTs in all three conditions (unshortened version)
Buchanan et al. (1994)	18 "deficit" schizophrenics (medicated); 21 "nondeficit" schizophrenics (medicated); 30 healthy controls	WR, CN, CWN	Total number of CWN items correctly completed (within time required to complete each card); controlled for overall performance differences in control participants	ANOVA on residual CN − CWN difference score	Deficit patients complete significantly fewer items in the CWN condition compared with nondeficit patients and controls; the latter two groups did not differ
Cantor-Graae et al. (1995)	14 schizophrenics (medicated); 14 healthy controls	CWN	Time required to complete the CWN card	Group comparison on CWN condition	Patients require significantly more time to complete CWN card
Verdoux et al. (1995)	18 schizophrenics (unmedicated then medicated); 18 healthy controls	WR, CN	Time required to complete each card	Group comparisons for each condition separately	Patients (unmedicated and medicated) and controls do not differ on WR; patients (unmedicated and medicated) require significantly more time to complete the CN card

Note. WR = word-reading condition; CN = color-naming condition; CWN = color-word naming or conflict condition; RT = reaction time; ANOVA = analysis of variance.

psychiatric control participants (Abramczyk, Jordan, & Hegel, 1983; Buchanan et al., 1994; Cantor-Graae, Warkentin, & Nilsson, 1995; Everett, Laplante, & Thomas, 1989; Golden, 1976; Killian, Holzman, Davis, & Gibbons, 1984; Verdoux, Magnin, & Bourgeois, 1995; Wapner & Krus, 1960; Wysocki & Sweet, 1985). Patients have also been shown to exhibit increased error rates in the conflict condition (e.g., Killian et al., 1984). These findings—increased RTs and error rates on the conflict condition—have been taken to suggest that patients exhibit increased Stroop interference, relative to healthy controls. However, as evident in Table 1, these studies vary in several important respects, such as testing for group differences on only the conflict condition, that complicate cross-study comparisons and lead to erroneous conclusions concerning schizophrenics' deficits on the Stroop task. We will address this concern in detail in the discussion and elucidate how methods for analyzing Stroop interference have given rise to erroneous conclusions suggesting that patients with schizophrenia exhibit an unequivocal excess in Stroop interference.

More recently, cognitive psychologists have employed single-trial versions of the Stroop task, in which individual stimuli are presented tachistoscopically and RT and accuracy data are coded for each trial, rather than estimated over the course of an entire card or series of trials. In addition to conferring increased precision in measurement of RT and greater freedom to manipulate stimulus conditions, this method has allowed the introduction of an additional condition. In this additional condition, the printed word and ink color are congruent (e.g., *RED* printed in red ink). First used in the single-trial version in 1969 (Sichel & Chandler, 1969), the congruent condition enables evaluation of another Stroop effect—facilitation—wherein color naming of color-congruent words is performed more quickly compared to a neutral condition, such as naming the color of a color-unrelated stimulus (e.g., *DOG* printed in red ink). Thus, with the addition of the congruent condition, two different aspects of the influence of words over color naming—Stroop interference and facilitation—can be assessed within the same individuals.[1]

Studies of patients with schizophrenia using single-trial versions of the Stroop task have all calculated difference scores, in which congruent and incongruent conditions are compared with the neutral condition. These studies have shown that patients exhibit increased RT facilitation (congruent RT vs. neutral RT) compared with healthy controls rather than increased RT interference (incongruent RT vs. neutral RT), as often inferred from studies employing card versions of the Stroop (Barch et al., 1996; Carter, Rpbertson, & Nordahl, 1992; Carter, Robertson, Nordahl, O'Shora-Celaya, & Chaderjian, 1993; Cohen, Barch, Carter, & Servan-Schreiber, in press; Schooler, Neuman, Caplan, & Roberts, 1997; Taylor, Kornblum, & Tandon, 1996). However, in single-trial studies, patients show increased interference as reflected in error rates rather than RT. That is, when compared with controls, patients exhibit a greater increase in errors from the neutral to the incongruent condition.

Findings from single-trial studies of schizophrenia are consistent with an increased influence of the word on the processing of color stimuli in patients relative to healthy controls. In prior work, we hypothesized that this effect in patients is due to a deficit in the ability to appropriately select the relevant stimulus dimension (i.e., print color). We also hypothesized that this selection deficit influences all task conditions, leading to a relative shortening of RTs in the congruent condition and a lengthening of RTs in the neutral condition (i.e., increased RT facilitation), as well as increased errors in the incongruent condition (i.e., increased error rate interference). For example, slowing on the neutral condition can occur when this condition contains lexical information and when patients have difficulty suppressing the prepotent or more automatic response tendency to read the word, rather than name its color. Such an effect would be reflected in lengthened RTs in the neutral condition. A more detailed discussion regarding the support for these hypotheses is provided in Barch, Carter, Usher, and Cohen (1998).

Thus, despite the conviction that attentional pathology is present in schizophrenia, it is clear that investigations using the card and single-trial versions of the Stroop task in such patients have yielded mixed and even conflicting conclusions. Further, investigators have often implicitly assumed that the two versions provide comparable measures of interference effects. Yet this assumption has not been tested directly and is at odds with the conflicting conclusions of increased RT interference on card versions and increased RT facilitation and error rate interference on single-trial versions.

The goals of this study are to further characterize performance of patients with schizophrenia on card and single-trial versions of the Stroop task and to critically evaluate previous card Stroop studies in order to reconcile the conflicting conclusions. Both versions of the task were administered to the same participants, eliminating ambiguities that may arise when comparing across studies (because of demographic and clinical differences in samples). Determining the relationships between the two versions of the Stroop task is important, given the continued use of this task in assessing selective attention deficits in schizophrenia and other disorders in which Stroop performance is often evaluated (Parkinson's disease, e.g., Henik, Singh, Beckley, & Rafal, 1993; Alzheimer's disease, e.g., Spieler, Balota, & Faust, 1996; Huntington's disease, e.g., Bamford, Caine, Kido, Plassche, & Shoulson, 1989).

Method

Participants

Participants were 55 schizophrenic ($n = 48$) or schizoaffective ($n = 7$) patients, as determined by *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994) criteria, and 24 healthy controls. All patients were actively psychotic, medicated inpatients at Mayview State Hospital who had been receiving the same medications and dosages for at least 2 weeks. Diagnoses were based on a semistruc-

[1] The congruent condition was not included in the original card Stroop because of concerns that participants would simply read the words and not attempt to name the colors.

tured interview for the Positive and Negative Syndrome Scale (Kay, 1991) and medical record review, conducted by two of the authors (W.M.P. and D.B.). Controls were recruited through local advertisements and were evaluated using the Structured Clinical Interview for *DSM–III–R* (*Diagnostic and Statistical Manual of Mental Disorders—Third Edition—Revised;* American Psychiatric Association, 1987). Control participants were excluded if they had any lifetime history of an Axis I psychiatric disorder, other than simple phobia (one control participant had a simple phobia), or any first-degree family history of psychotic disorders. Both patients and controls were excluded for the following reasons: substance abuse within the previous 6 months, neurological illness or history of head trauma with loss of consciousness, mental retardation, nonnative English speaker, and color blindness. All participants provided written informed consent in accordance with the University of Pittsburgh and Mayview State Hospital institutional review boards. All participants were paid for their participation.

Demographic and clinical characteristics are provided in Table 2. Control participants were matched, on average, with patients for age, gender, and years of parental education (to match approximately for socioeconomic status) and did not significantly differ on any of these variables. Although patients differed significantly from controls on personally achieved levels of education, $F(1, 77) = 46.8$, $p < .0001$, the two groups were matched on parental education. Matching on the latter reduces the potential of matching patients and controls on a potentially important consequence of the disease process, since schizophrenia clearly influences educational achievement. Daily oral doses of anti-psychotic medications for patients were converted to chlorpromazine equivalents according to guidelines suggested by Davis, Janicak, Linden, Moloney, and Pavkovic (1993). Depot doses were converted to average daily doses using guidelines suggested by Baldessarini (1985).

Card Stroop

The three-card version of Golden (1978) was used. All cards contained five columns of 20 items each. Participants were required to complete as many items as possible within a 45-s time limit. In fixed order, participants first read color words printed in black (word-reading condition), then named the printed color of color patches (consisting of *XXXX;* color-naming condition), and finally, named the printed color of color-incongruent words (color-word naming or conflict condition).

Single-Trial Stroop

Stimuli were identical to those used by Carter et al. (1992) and consisted of 96 trials: 24 (25%) congruent trials, 24 (25%) incongruent trials, and 48 (50%) neutral trials. Each trial consisted of a word printed in one of four colors: red, blue, green, or purple. Congruent stimuli consisted of one of the four color names presented in its own color. The incongruent stimuli consisted of one of the four color names presented in one of the three remaining colors. Neutral stimuli were one of four color-unrelated words (dog, bear, tiger, or monkey) printed in one of the four colors. The neutral words matched the four color words in length (letters and syllables) and frequency and were derived from a single semantic category to eliminate semantic confounds.

Stimuli were presented singly in the middle of the video screen with an intertrial interval of 4,000 ms. They remained on the screen until the participant responded or until a fixed response period of 2,000 ms elapsed. The stimuli were then replaced by a fixation cross that remained until the next stimulus. Verbal responses were tape-recorded for later coding of performance accuracy.

Procedure

Participants were tested individually and order of task presentation was approximately counterbalanced across participants. For the card Stroop, participants were instructed to perform each card as quickly and accurately as possible. When participants made errors, they were instructed to correct their response, although explicit error data were not recorded. Stimuli for the single-trial Stroop were presented on an Apple Macintosh computer using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Reaction times for onset of word articulation were automatically recorded by the computer to millisecond accuracy using a microphone and voice-activated relay. For each task, a short 2- to 3-min practice period preceded actual testing to assure that participants understood the instructions, were comfortable with the apparatus, and were performing the task appropriately.

Data Analysis

The primary dependent variables from the card Stroop were the number of items completed on each card within the 45-s time limit. A 2 × 3 analysis of variance (ANOVA) with group as the between-subjects factor and condition (word reading, color naming, or conflict) as the within-subject factor was conducted to determine overall group effects. More importantly, planned between-group comparisons evaluated interference effects by employing only the color-naming and conflict conditions. Single-trial Stroop data were evaluated separately for effects of RT and error rate. For analysis of RT, medians (with responses below 200 ms excluded) for correct responses were used. Reaction time and error rate data

Table 2
Demographic Characteristics of Schizophrenic and Healthy Control Participants

Participants' characteristics	Schizophrenic patients (n = 55)		Healthy controls (n = 24)	
	M	*SD*	*M*	*SD*
Age (yrs)	38.5	8.8	35.5	5.4
% male	54.0		56.0	
Parent education (yrs)	12.1	2.9	12.4	1.9
Education (yrs)[a]	11.9	1.6	15.0	2.2
Length of current hospitalization (days)	417.0	628.0		
Age of first hospitalization (yrs)	21.5	6.6		
Length of illness (yrs)	20.5	7.6		
Chlorpromazine equivalents	1,344.0	1,577.0		

[a]Patients and controls differed significantly on years of educational achievement, $F(1, 77) = 46.8$, $p < .0001$.

were analyzed using a 2 × 3 ANOVA, with group as the between-subjects factor and condition (incongruent, neutral, or congruent) as the within-subject factor. Between-group planned comparisons evaluated interference (neutral vs. incongruent) and facilitation (neutral vs. congruent) effects. For all analyses, the Greenhouse-Geisser (1959) epsilon correction was applied when there was more than one level of a factor to correct for violations of sphericity. Corrected p values and uncorrected *dfs* are reported throughout.

An additional series of analyses was conducted to address the issue of generalized versus differential deficit, because studies of schizophrenic patients are often confounded by the effects of generally poorer performance by patients than controls across experimental conditions. With respect both to RT and accuracy, difference scores can be spuriously inflated in participants who exhibit overall worse or more variable performance, or both (Chapman, Chapman, Curran, & Miller, 1994). Further, patients with schizophrenia generally perform worse under conditions that are also more difficult for controls. Thus, a finding that patients exhibit overall worse performance in combination with either increased interference or facilitation might suggest that patients suffer from a generalized rather than a differential deficit. A number of analytic methods have been employed to address this possibility. For example, several studies have conducted analyses on subsets of participants within each group by including only patients and controls that performed similarly on the neutral, control task (Carter et al., 1992; Taylor et al., 1996). However, this approach has been criticized on a number of grounds, including statistical (e.g., regression-to-the-mean effects; Chapman & Chapman, 1973) and subject-characteristic issues (e.g., systematic unmatching on unknown variables; Meehl, 1971). Although not entirely optimal (see, e.g., Chapman & Chapman, 1989; Miller, Chapman, Chapman, & Collins, 1995), the possibility of a generalized deficit was examined by following the suggestions of Chapman et al. (1994) to determine whether patients perform differently on two tasks from what would be predicted on the basis of general performance level.

Finally, correlational analyses were conducted to determine relationships among the two tasks on measures of interference. Data entered into these analyses were difference-score measures of interference (card Stroop: conflict − color naming; single-trial Stroop: incongruent − neutral), as measured by RT and number of items completed, respectively, for the single-trial and card Stroop task.

Results

Card Stroop

Means and standard deviations of the number of items completed for each card among each group are provided in Table 3. The Group × Condition ANOVA revealed significant main effects of group, $F(1, 77) = 54.08, p < .0001$, and condition, $F(2, 154) = 398.88, \epsilon = .83, p < .0001$. Patients completed fewer items than did controls across conditions, and both groups showed a nearly linear decrease in item completion from word reading to color naming to color-word naming. There was also a trend toward a significant Group × Condition interaction, $F(2, 154) = 2.69, \epsilon = .83, p < .082$. More important, planned contrasts testing group differences in interference revealed a significant Group × Condition (color naming or color-word naming) interaction resulting from less interference in patients than controls, $F(1, 77) = 5.12, p < .027$. Thus, although both groups exhibited significant interference—controls: $F(1, 23) = 225.08$, patients: $F(1, 54) = 262.34$, $ps < .0001$—patients showed significantly less interference than controls (Figure 1). It is possible, however, that the interference effect reflects, in part, poorer performance on the color-naming task, because the two groups differed significantly on this condition as well, $F(1, 77) = 51.98, p < .0001$.

An additional analysis of the Stroop interference effect followed the "ratio" method suggested by Graf, Uttl, and Tuokko (1995). The ratio of color-word/color was calculated under the premise that the denominator partials out effects of overall speed of responding. Results of this ANOVA, with group as the between-subjects factor, showed that patients and controls did not differ significantly on this measure of interference, $F(1, 77) = 2.35, p > .12$ ($M \pm SD$ for controls = $.64 \pm .10$, for patients = $.59 \pm .16$).

Single-Trial Stroop

Means and standard deviations for RT and error rate for the three conditions and two groups are shown in Table 3

Table 3
Mean Number of Items Completed for the Card Stroop and Reaction Time and Accuracy for the Single-Trial Stroop

Test and variable	Controls *M*	Controls *SD*	Schizophrenics *M*	Schizophrenics *SD*
Card Stroop: No. items completed				
Word	91	16	73	16
Color	76	12	51	15
Color-Word	49	11	29	9
Single-trial Stroop: Reaction time (ms)				
Congruent	642	20	837	179
Neutral	692	90	950	180
Incongruent	815	180	1,049	201
Single-trial Stroop: Accuracy				
Congruent	.995	.019	.989	.023
Neutral	.987	.019	.978	.036
Incongruent	.948	.078	.846	.136

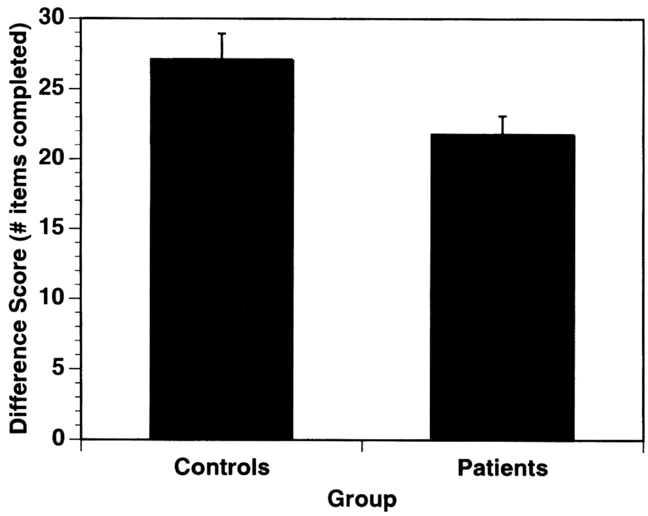

Figure 1. Mean ($\pm SE$) card Stroop interference (color-word condition − color condition) in schizophrenic patients and healthy controls.

(center and bottom, respectively). The Group × Condition ANOVA on RT yielded significant main effects of group, $F(1, 77) = 36.66$, $p < .0001$, and condition, $F(2, 154) = 111.45$, $\epsilon = .87$, $p < .0001$. Controls performed faster than patients, and in comparison to neutral stimuli, both groups of participants responded faster to congruent stimuli, $F(1, 77) = 55.68$, $p < .0001$, and more slowly to incongruent stimuli, $F(1, 77) = 79.39$, $p < .0001$. There was also a near-significant trend toward a Group × Condition interaction, $F(2, 154) = 3.00$, $\epsilon = .87$, $p < .06$. Planned comparisons indicated that patients showed significantly more facilitation than controls, $F(1, 77) = 8.22$, $p < .006$, but the two groups did not differ in interference, $F(1, 77) = 0.92$, $p < .34$ (Figure 2). Analysis of ratio scores (interference = incongruent − neutral/neutral; facilitation = neutral − congruent/neutral) similarly demonstrated that patients showed significantly greater facilitation than controls, $F(1, 77) = 4.23$, $p < .04$ ($M \pm SD$ for controls = $1.08 \pm .08$, for patients = $1.14 \pm .12$). But, unlike the difference-score measure wherein the two groups did not differ in interference, patients showed significantly less interference than controls, $F(1, 77) = 6.17$, $p < .02$ ($M \pm SD$ for controls = 1.18 ± 0.12, for patients = 1.11 ± 0.11).

Error rate data were similarly evaluated, yielding an ANOVA with significant main effects of group, $F(1, 77) = 9.89$, $p < .0025$, and condition, $F(2, 154) = 42.38$, $p < .0001$. Patients performed less accurately than controls, and both groups of participants performed more accurately to congruent stimuli, $F(1, 77) = 6.52$, $p < .013$, and less accurately to incongruent stimuli, $F(1, 77) = 40.52$, $p < .0001$, relative to neutral stimuli. The Group × Condition interaction was also significant, $F(2, 154) = 11.50$, $\epsilon = .55$, $p < .001$. Planned comparisons indicated that patients showed greater decreases in accuracy in the incongruent condition compared to neutral stimuli, $F(1, 77) = 11.93$, $p < .001$ (i.e., error rate interference), whereas the two groups did not differ on error rate facilitation, $F(1, 77) = 0.16$, $p < .70$ (Figure 3). Analyses of ratio data yielded similar results: The two groups did not differ on error rate facilitation, $F(1, 77) = 0.23$, $p > .60$ ($M \pm SD$ for controls = $.992 \pm .018$, for patients = $.989 \pm .035$), but did differ significantly on error rate interference, $F(1, 77) = 12.19$, $p > .001$ ($M \pm SD$ for controls = $.961 \pm .081$, for patients = $.863 \pm .126$). Thus, relative to controls, patients exhibited deficits in Stroop performance that were reflected in increased facilitation, as measured by RT, and increased interference, as measured by errors.

Regression Analyses

As expected, patients exhibited generally poorer performance than controls across all conditions, possibly leading to spuriously inflated RT and accuracy difference scores (Chapman et al., 1994). Specifically, patients exhibited greater RT facilitation scores than controls on the single-trial Stroop task and showed generalized slowing across all conditions on both tasks. Further, patients performed worse under conditions that were also more difficult for controls, as reflected in the error rate interference scores on the single-trial Stroop task. These factors might suggest that the greater

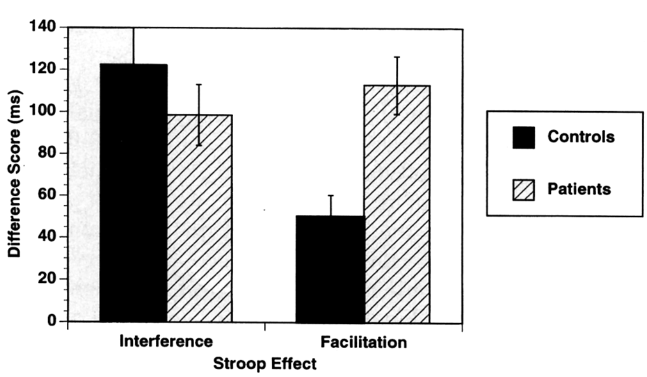

Figure 2. Mean ($\pm SE$) reaction time interference (incongruent − neutral) and facilitation (neutral − congruent) for schizophrenic patients and healthy controls obtained on the single-trial Stroop task.

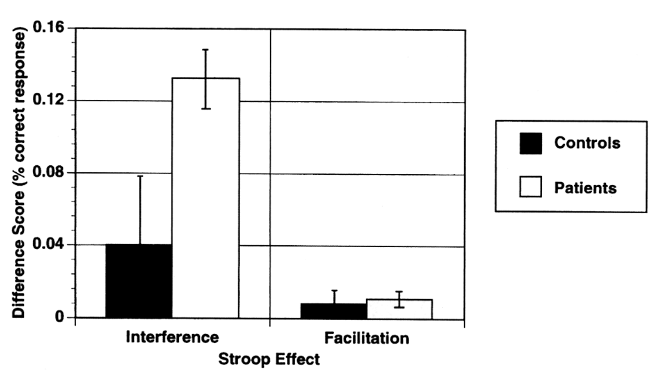

Figure 3. Mean ($\pm SE$) error rate interference (incongruent − neutral) and facilitation (neutral − congruent) for schizophrenic patients and healthy controls obtained on the single-trial Stroop task.

facilitation among the schizophrenic patients simply reflects an artifact of their longer RTs (i.e., a generalized deficit) and not a cognitive deficit specific to the facilitation effect.

To examine the influence of this potential confound, we computed regression equations that predicted the measures of interest from control measures, using only data from control participants. For the card Stroop, we computed the regression equation that predicted interference scores (conflict − color naming) from a measure of overall performance (color naming + conflict). For the single-trial Stroop RTs, we computed the regression equation that predicted interference scores (incongruent RT − neutral RT) from a measure of overall RT (incongruent RT + neutral RT) and facilitation scores (neutral RT − congruent RT) from overall RT (congruent RT + neutral RT). Accuracy effects were not evaluated in this manner, given that there was not sufficient variance in the neutral condition for it to serve as a useful predictor of overall performance. If a significant association between the measures of interest and the control measure was found, we computed residuals (observed − predicted) for all participants using the equation derived from the controls. Then, follow-up focused between-group contrasts were conducted on these residuals. These contrasts take into account the overall level of performance in determining the effect of interest.

For the card Stroop, the regression analyses indicated no significant association between interference and overall performance among controls ($p < .60$). For the single-trial Stroop, there was no significant association between overall RT and RT facilitation ($p < .50$), but there was a near-significant positive association for RT interference ($\beta = .16$, $p < .08$). Analysis of the residuals showed patients exhibited significantly less interference than did controls when taking into account the overall level of performance, $F(1, 77) = 17.14$, $p < .0001$.

We also conducted regression analyses identical to those employed by Buchanan et al. (1994), given that statistical artifacts can arise when regressing a difference score on the sum of the two conditions from which the difference score was obtained (e.g., Assor & Tzelgov, 1987; Assor, Tzelgov, Thein, Ilardi, & Connell, 1990). Using the method of Buchanan et al., we first regressed the incongruent (or congruent) scores on the neutral scores for the controls and applied the resultant regression weight to patients' performance in the neutral condition to estimate their performance in the incongruent (or congruent) condition. Interference (or facilitation) reflected the residual (i.e., observed − estimated) of the incongruent (or congruent) scores. Results of these analyses were identical to results using the approach described above, with the exception that patients' performance on the card Stroop showed only a trend toward lesser interference than did performance of controls, $F(1, 77) = 3.03$, $p < .09$.

It is important to note that statistical-control methods cannot overcome artifactually produced group differences stemming from psychometric aspects of the task (Chapman & Chapman, 1973, 1989; Miller et al., 1995). However, these findings suggest that even after accounting for differences in overall performance, increased RT facilitation, evidenced in the single-trial Stroop task among schizophrenic participants, is not simply an artifact of their slower RTs.

Relations Among Card and Single-Trial Stroop Tasks

Pearson product-moment correlational analyses were conducted on each group separately to determine relationships among interference measures for each of the two tasks. For the card Stroop, the measure was the conflict − color-naming difference score. For the single-trial task, the measures were (a) incongruent RT − neutral RT difference score for RT interference and (b) incongruent error rate − neutral error rate difference score for error rate interference. These measures did not significantly correlate within either the schizophrenic patients ($r = -.02$, $p < .90$) or the controls ($r = .12$, $p < .58$). Linear and polynomial regression analyses (up to fourth-order) revealed that the absence of a correlation among these measures was not due to the presence of nonlinear relationships ($ps > .30$).

Discussion

The primary aim of this study was to compare and contrast the performance of healthy controls and patients with schizophrenia on card and single-trial versions of the Stroop task. A second goal was to determine relationships among Stroop interference on these two tasks and to reconcile conflicting assertions in the literature. We observed significant group differences both within and between the two measures. On the card Stroop, patients exhibited significantly less interference relative to healthy control participants, as measured by the difference in the number of items completed in the neutral and conflict conditions. On the single-trial Stroop, patients did not differ from healthy controls on RT interference, as measured by difference scores. Instead, and consistent with previous findings using the single-trial versions of the task, patients exhibited significantly greater RT facilitation (Barch et al., 1998; Carter et al., 1992, 1993; Cohen et al., in press; Taylor et al., 1996). Evidence of greater interference in patients on the single-trial Stroop was evident, not in RT difference scores, but in error rates, a measure infrequently obtained from card versions of the task. That is, compared with healthy controls, patients exhibited a significantly greater increase in errors from the neutral to incongruent trials, but no differences in error rate facilitation. Because we followed the Golden (1978) procedure for the card Stroop, which does not record errors on the card Stroop, we cannot assess relationships among the two versions on interference as reflected in accuracy. However, our anecdotal observations were that patients clearly made more errors than did controls across all conditions. Finally, correlational analyses comparing RT interference measures on the two tasks did not reveal significant linear or nonlinear relationships.

At first glance, our card Stroop findings appear to be at odds with the general impression from previous studies using similar versions of the Stroop task (Buchanan et al., 1994; Cantor-Graae et al., 1995; Everett et al., 1989;

Golden, 1976; Killian et al., 1984; Verdoux et al., 1995; Wapner & Krus, 1960; Wysocki & Sweet, 1985). These studies have typically concluded, or have been interpreted by others to suggest, that patients exhibit greater interference effects when compared with controls. However, few of these studies have convincingly demonstrated that schizophrenic patients as a group exhibit a reliable increase in Stroop interference; instead, we suggest that the conclusions drawn from most, but not all, of these previous studies are erroneous in suggesting that patients exhibit enhanced interference effects relative to healthy controls. That is, we propose that the commonly accepted view of increased Stroop interference—reflected in increased RTs—is overstated and is not as strongly supported by the literature as is assumed. Although there are studies that have established such a finding using card versions of the Stroop task, the majority of studies have yielded results that are less supportive of this conclusion. As we discuss below, several factors may account for the differences in conclusions. Further, the findings from the single-trial Stroop present a paradox to classical neuropsychological studies that employ card versions of the Stroop task. That is, our sample of schizophrenic patients did exhibit deficits on the single-trial Stroop task, but the more frequently measured Stroop effect in neuropsychological evaluations—longer response times to incongruent compared with neutral stimuli—was not significantly excessive. Instead, facilitation of response times to congruent relative to neutral stimuli and error rate interference appear to be the reliable deficits found in schizophrenic patients on single-trial versions of the Stroop.

What accounts for the differences between the results and conclusions reached from single-trial and card Stroop studies? We propose that the differences can be accounted for by the consequences of two general factors: (a) the method of deriving Stroop interference measures and (b) the mode of stimulus presentation.

Methods for Deriving Interference Scores

Two primary approaches have been employed to measure Stroop interference: (a) between-group comparisons on each condition separately; and (b) computation of difference scores, wherein interference is reflected in the conflict − color naming difference. We suggest that it is this analytic discrepancy that accounts for most of the conflicting conclusions. Most card Stroop studies of patients with schizophrenia have determined the presence of interference effects by using pairwise comparisons, in which the presence of group differences is evaluated for each condition separately. For example, all but two studies cited in Table 1 used such an approach. These studies have taken the significantly greater RTs on the conflict-only condition in patients compared with controls to reflect greater RT interference in patients. The remaining two studies had additional ambiguity in their analysis procedures. Killian et al. (1984) derived an "interference" score by calculating difference scores between color-naming and word-reading conditions, excluding the conflict condition altogether. Wapner & Krus (1960) did employ an ANOVA and obtained a significant Group × Condition interaction. However, all three conditions were entered into the ANOVA, so the source of this interaction is uncertain. As follow-up tests, these authors conducted pairwise comparisons of the sort that are being discussed. Of the studies cited in Table 1, only one study (Abramczyk et al., 1983) evaluated the significance of interference effects by calculating the conflict − color naming difference score, the primary analytic approach used in our study. However, these authors transformed their raw data in a nonlinear manner[2] and when reevaluated without the transformation, the finding of increased interference in patients is eliminated and actually reversed. That is, using raw scores, patients exhibit less interference than controls. The study by Buchanan et al. (1994) did demonstrate significant increased interference in a subset of patients—deficit compared to nondeficit patients and healthy controls. These authors employed an analytic approach that was similar but not identical to the one used in the present study in order to statistically account for the possibility that patients exhibited an overall generalized deficit (i.e., generalized slowing); that is, they measured Stroop interference as the color − color–word difference score and used a regression approach inspired by Chapman et al. (1994).

Testing for group differences on only the conflict card does not directly evaluate group differences in Stroop interference. It has been argued (e.g., Henik, 1997; MacLeod, 1991) that interference reflects the intrusion of the task-irrelevant stimulus dimensions on the processing of the relevant dimension. Evaluation of this intrusion requires estimation of "baseline" performance on the relevant dimension (i.e., color naming) in the absence of competing, irrelevant sources (i.e., word reading). Similarly, evaluating group differences in Stroop interference (or facilitation) requires determining whether one group displays a disproportionate impairment (or improvement) of performance in the conflict condition, as compared with performance in a neutral condition.[3] Therefore, when using a single pairwise comparison of conflict–card performance, one cannot deter-

[2] It is important to note that the data transformation used by these authors actually reversed the results obtained using the raw data (number of items completed). Abramczyk et al. (1983) estimated a mean RT using the following formula: (45/number of items completed correctly) × 1,000. With this transformation, patients displayed greater interference than controls. However, patients displayed less interference than controls when using the number of items completed, which is the same dependent variable and result in our study. Applying this transformation to our card Stroop data similarly results in greater estimated RT interference in patients compared with controls in the analysis of difference scores, $F(1, 77) = 18.12, p < .0001$.

[3] It should be noted that the choice of the neutral condition may have measurable effects on baseline performance and hence on estimates of interference and facilitation effects (e.g., Jonides & Mack, 1984). In a separate study (Barch et al., 1998), we have shown that, compared with normal individuals, schizophrenic patients show the same pattern of single-trial Stroop performance reported in the present study (increased RT facilitation and increased error interference) using both lexical and nonlexical neutral stimuli.

mine whether findings of impaired performance represent a generalized deficit that may be equally apparent in all conditions or a deficit more specific to the selection of task-relevant information. In the present study, the analysis of RT interference effects using only a group comparison for the conflict condition would have led to the erroneous conclusion that patients indeed exhibit increased RT interference on both the card, $F(1, 77) = 67.32$, $p < .0001$, and single-trial Stroop, $F(1, 77) = 28.19$, $p < .0001$. However, such a conclusion would clearly have been incorrect, given that patients' RTs were not disproportionately longer in the conflict as compared with the neutral condition.

We further illustrate this point using the data presented in Table 4, which shows the group means for each card Stroop condition that were provided in their respective reports, as well as the color naming − color-word naming difference scores calculated from these means. Studies not included in Table 4 did not provide means for each of the two critical conditions (i.e., color naming and color-word naming). Of the five studies cited, four concluded on the basis of between-group comparisons that patients showed greater interference than controls (see Table 1). However, evaluation of difference scores shows that for two of the studies (Golden, 1976; Wysocki & Sweet, 1985) patients showed less interference than controls. Of the remaining three studies shown in Table 4, Everett et al. (1989) employed the nonlinear transformation described in Footnote 2, but when the data are transformed to the number of items completed within the time limit (parenthesized numbers), patients actually show less interference than controls. Thus, only two studies cited in Table 4 (Abramczyk et al., 1983; Wapner & Krus, 1960) show evidence for increased interference in patients relative to controls. Although not included in Table 4 because condition means were not provided, the study by Buchanan et al. (1994) did demonstrate significant interference in deficit patients, as described earlier.

Relationship Between Card and Single-Trial Stroop Tasks

Our results showed that patients exhibited less RT interference than did healthy controls on the card Stroop and that the two groups did not differ in RT interference on the single-trial Stroop. Further, measures of RT interference did not correlate between the two tasks. We propose that several important methodological differences between the two versions of the Stroop task account for this difference and must be considered when evaluating measurement of Stroop effects. The major methodological difference between the two tasks is the manner of stimulus presentation. In card versions, all stimuli for a condition are presented simultaneously on the same card (i.e., blocked conditions). In contrast, in single-trial versions of the Stroop task, only one stimulus is presented at a time, and in each block-trial conditions are mixed. The mode of stimulus presentation for the card Stroop has at least four consequences. One consequence concerns the reliability of measurement. Specifically, the card Stroop, as typically employed in neuropsychological studies, yields an index of performance for each condition derived from only a single measurement, because each card is typically administered once. In contrast, the single-trial Stroop requires the administration of many trials, and therefore yields a measure of performance with greater reliability.

A second consequence is the introduction of nonspecific sources of interference or additional task requirements. A rudimentary analysis of task demands suggests that card-Stroop performance requires, minimally, that participants (a) maintain visual scanning of lists, (b) switch from item to item and from column to column, and (c) select the stimulus to be named from an array of stimuli on the card. Thus, in addition to requiring word reading and color naming, the card Stroop requires processes involved in maintaining

Table 4
Means for Each Card Stroop Condition From Studies That Provided Such Data

Study and group	WR	CN	CWN	CN − CWN difference
Wapner & Krus (1960)				
Control	39.2	57.1	98.0	40.9
Patient	56.9	78.2	151.2	73.0
Golden (1976)				
Control	112.0	81.7	41.3	40.4
Patient	97.9	72.4	35.9	36.5
Abramczyk et al. (1983)				
Control	43.3	60.0	100.5	41.5
Patient	50.2	77.4	139.6	62.2
Wysocki & Sweet (1985)				
Control	103.1	70.6	40.0	30.6
Patient	86.5	53.4	30.2	23.2
Everett et al. (1989)[a]				
Control	372.0 (121.0)	562.0 (80.1)	952.0 (47.3)	390.0 (32.8)
Patient	593.0 (75.9)	977.0 (46.1)	1,990.0 (22.6)	1,013.0 (23.5)

Note. WR = word-reading condition; CN = color-naming condition; CWN = color-word naming or conflict condition.
[a]These authors transformed the data using the transformation described in Footnote 2; numbers in parentheses reflect the number of items completed within the 45-s time limit.

focus on each stimulus and ignoring the interfering or distracting effects of neighboring stimuli. Although it might be that these nonspecific factors would cancel one another out when a difference score is computed, it is conceivable that such nonspecific factors play a greater role in the incongruent condition than in either the neutral or word-reading conditions. Results of several studies suggest that this might indeed be the case, particularly in participants who are less proficient at narrowing their focus on target items and ignoring the surrounding items. For example, Henik, Tzelgov, Cohen, and Henik (1997) showed that young children exhibited greater interference on a card version of the Stroop task compared with a single-trial version, whereas they did not show differences in RT between the two versions of the task on the neutral condition. A similar suggestion was made earlier by Schadler and Thissen (1981). Such a suggestion would have operated in favor of finding greater Stroop interference in patients compared with controls if the patients were unable to "narrow their focus." In contrast, the single-trial version does not require such processes and therefore maintains greater control over sources of interference associated with "irrelevant" stimulus dimensions. The single-trial version, therefore, provides a more "pure" measure of interference because of the effects of word reading on color naming. Thus, the increased interference of patients questionably shown in most studies using the card Stroop may reflect more generalized performance deficits associated with non-specific factors in addition to deficits associated with selecting the appropriate stimulus dimension.

A third consequence of card Stroop presentation is the confounding of RTs and errors. Specifically, although data on error rates can be obtained on the card Stroop, overall RTs on this task inextricably reflect a combination of correct and incorrect responses, which is particularly problematic in versions of the Stroop task that require participants to correct mistakes during task performance (Golden, 1978). In such versions, it is often unclear whether (a) poor performance is due to slow correct responses or to a greater number of errors and (b) distribution of slow correct responses and errors differs across conditions. As illustrated by the data from single-trial Stroop studies, impaired performance among schizophrenic patients may be differentially reflected in either slow correct responses (i.e., the neutral condition) or increased errors (i.e., the incongruent condition). Thus, it is important to have clear, unconfounded measures of both RT and errors to completely evaluate selective attention pathology in schizophrenia.

A fourth consequence of stimulus presentation mode relates to the blocked (card Stroop) versus mixed (single-trial Stroop) presentation of stimulus conditions. Although the single-trial task can be designed to present stimulus conditions in separate blocks of trials, we used a mixed design in our study. This blocked-versus-mixed difference between the two versions of the task can give rise to important strategic differences underlying performance of the two tasks because of differences in "set" or context effects. The card version of the Stroop facilitates the formation of set effects that, over time, may make it easier for participants to overcome the influence of the word, resulting in reduced interference effects. Such set effects are less likely to operate in mixed versions of the task and are, therefore, less likely to reduce consequent interference (or facilitation) effects. Thus, differences in the formation of stimulus or response set effects (or both) are important considerations.

Conclusion

Using the card Stroop, we failed to find increased RT interference in a large, carefully characterized group of patients with schizophrenia. On the surface, this finding appears inconsistent with conclusions from prior card Stroop studies. However, when the literature is subject to careful scrutiny, it is clear that few of these earlier studies have convincingly demonstrated that patients with schizophrenia, as a group, show evidence of greater interference on the card Stroop when compared with healthy control participants. However, consistent with previous studies, patients did exhibit increased RT facilitation scores as well as increased error rate interference on the single-trial Stroop task. These results point to the importance of obtaining both RT and accuracy measures of Stroop-task performance. Further, the increase in errors on the interference condition may reflect a better index of interference effects in schizophrenia, given that error rates are not influenced by potentially confounding effects of slower RTs. In sum, it is clear that single-trial versions of the Stroop task are more sensitive measures of selective attention pathology in patients with schizophrenia.

We discussed several possible sources of differences between results using card and single-trial versions of the Stroop task and believe that single-trial versions offer advantages over card versions in isolating selective attention deficits in schizophrenia. We propose that single-trial versions be the preferred method when using the Stroop task to investigate selective attention pathology in schizophrenia.

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