Schizophrenia and the Stroop Effect

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Conflict between irrelevant words and relevant colors in the Stroop task creates interference, long considered a measure of how well individuals focus attention. In the traditional card version of the Stroop task, schizophrenia patients exhibit increased interference, consistent with the distractibility they exhibit in everyday life. In contrast, on other versions of the Stroop task they show augmented facilitation (faster responding to congruent than to neutral trials). We suggest that schizophrenia patients possess adequate attentional resources to avoid interference when each letter string is presented individually but face difficulty when delays are imposed and multiple attentional demands appear. Although psychiatric symptomatology may contribute to different patterns of performance, there is no evidence that medication modulates this.

Key Words: schizophrenia, Stroop, selective attention

The original study of color-word interference by J. R. Stroop (1935) has generated a vast amount of research in cognitive psychology (see MacLeod, 1991, for a review) and in clinical psychology (see Williams, Mathews, & MacLeod, 1996, for a review). In particular, the Stroop paradigm has been employed frequently in neuropsychology and neuropsychiatry. The Stroop task measures competition between dimensions and is probably one of the most widely used tests in neuropsychology. The value of using this test lies not only in its long history but also in the many studies that have been conducted to understand the underlying components of the test. The use of the Stroop test in psychiatric patients, such as those diagnosed with schizophrenia, has yielded important data concerning attentional function in clinical populations and was a principal factor that motivated us to write this review. In addition, we hoped that such a review could generate insights related to the cognitive operations involved in the Stroop task as well as to selective attention in general.

This selective review emphasizes studies that examine the relation between the Stroop effect and components of the Stroop effect in patients with schizophrenia. For the most part, the review does not include studies that (a) employed the Stroop effect to screen subjects (Heilbrun, 1973); (b) used Stroop conditions to create a composite score, for example, a 'frontal score' (Stam et al., 1993); or (c) used only one component of the Stroop task as the dependent variable (McCormick, Toland, & O'Neill, 1980; Porterfield & Golding, 1985). In the latter case, when only the incongruent condition is used, it is not possible to look at interference, facilitation, or an overall congruency effect (incongruent minus congruent), all of which are of central interest in the current review. To assist the reader, we have provided summaries throughout the review.

THE STROOP PARADIGM

Stroop (1935)

As mentioned earlier, the Stroop task is included in many neuropsychological batteries as a measure of selective attention. Unfortunately, despite its wide application, the task is sometimes misapplied (Henik, 1996). Many studies conducted in clinical populations are not motivated by a conceptual framework, but rather by empirical diagnostic criteria. To illustrate the concep-

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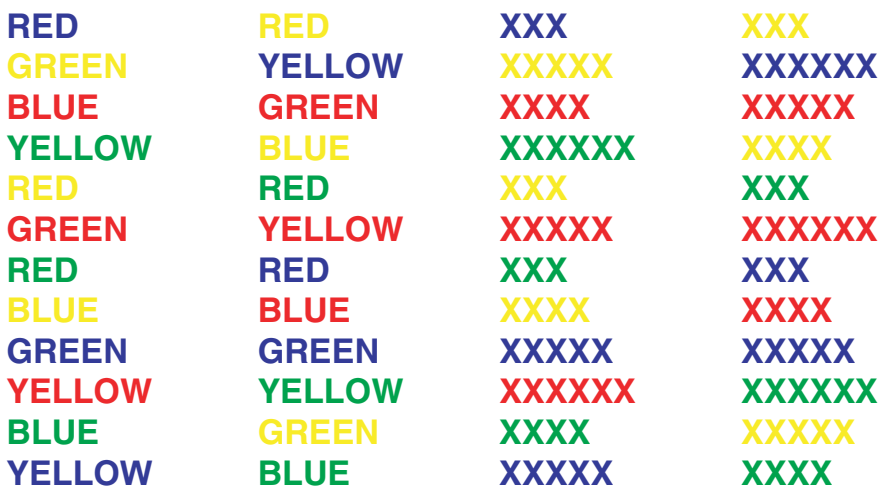

Figure 1: The Card Version of the Stroop Task.
NOTE: The two leftmost columns contain incongruent stimuli and the two rightmost columns contain neutral stimuli. In his 1935 work, Stroop used patches of color, rather than series of letters, for the neutral condition. The two conditions are presented, to participants, on separate cards. In both conditions, participants are asked to name the color of the ink of each stimulus without stopping.

tual framework that underlies this widely used attention task, we will now describe and discuss Stroop's original study.

J. R. Stroop was interested in creating an experimental method that would allow for the measurement of interference of one dimension on another. His landmark paper (1935) described three experiments. Across experiments, subjects were presented with words in black, patches of color, or words in color on a paper (see Figure 1). The subjects were asked to read the words or to name the colors as fast as possible. Overall response time (RT) to perform the task was then measured (in seconds for 50 or 100 responses on a single card). In all experiments, five colors were employed: red, blue, green, brown, and purple.

The first experiment measured "the effect of interfering color stimuli upon reading names of colors serially" (p. 647). Accordingly, it was composed of two conditions: names of colors in black ink (e.g., the word *red* in black) and color words in an incongruent ink (e.g., the word *red* in purple). Subjects were asked to read the words and ignore their colors. Stroop referred to the first condition as "reading color names printed in black" (RCNb) and to the second condition as "reading color names where the color and the word are different" (RCNd). The first condition (RCNb, word reading condition) is typically employed to look at general differences in word reading and only infrequently to look at the reverse Stroop effect (Abramczyk, Jordan, & Hegel, 1983). To study the reverse Stroop effect, it is necessary to add an incongruent condition and ask participants to read the words and ignore the colors. Moreover, authors sometimes compare reading color words in black (RCNb) with naming color words (NCWd), which confounds two sources of interference and two types of task. Others refer to the incongruent condition itself, with no comparison to any baseline condition, as a measure of interference. As interference is, by definition, a difference score between a baseline measure and a conflict condition, presentation of the conflict condition in isolation will not produce an accurate measure of interference. On average, participants read the 100 color names in the incongruent condition only slightly slower than they read the same names printed in black. Stroop concluded that this effect was not reliable, and additional experiments replicated this finding (MacLeod, 1991).

The second experiment is the famous one. Here, Stroop measured "the effect of interfering word stimuli upon naming colors serially" (p. 649). This experiment was also composed of two conditions: squares of colors (e.g., a square of red color) and the same incongruent condition as used in the first experiment. Participants were asked to name the colors and to ignore the words. The first condition was termed "naming color test" (NC), and the second condition was termed "naming color of word when the color of the print and the content of the word are different" (NCWd). On average, the subjects named the colors in the incongruent condition much slower (47 seconds longer) than they named the patches of colors. Stroop (1935) concluded that this was a reliable difference. Many authors refer to the effect generated in the second experiment (e.g., the interference of an irrelevant word on naming color) as the "Stroop effect." The effect generated in the first experiment (e.g., the interference of the irrelevant color on

reading the words) is termed the "reverse Stroop effect." It is important to note that in the first two experiments Stroop measured interference with appropriate neutral trials designed to suit the task (i.e., words in black for reading and patches of color for color naming).

The third experiment was designed to explore "the effects of practice upon interference." In this experiment, subjects practiced naming colors mainly by working with the incongruent condition (NCWd) for 8 days. Although the Stroop interference effect was still sizeable even after 8 practice days, it was clear that practice reduced the interference of the word on color naming. Stroop suggested that this pattern of results was because of training and the nature of the associations between word stimuli and reading on one hand and between color stimuli and naming responses on the other hand. It should be noted that Stroop was the first to demonstrate the reverse Stroop effect, which was found in this experiment.

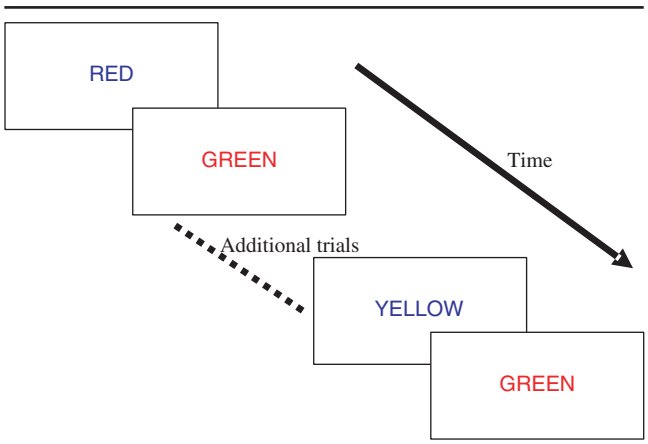

Figure 2: Single-Trial Version of the Stroop Task.
NOTE: Each display (trial) presents a single word in color. Participants are asked to name the ink color of the individual word that appears on the screen.

Two Major Versions of the Stroop Task

There are two major variations in administering the Stroop task: a card version and a single-trial version (MacLeod, 1991; Salo, Henik, & Robertson, 2001). In the card version (see Figure 1), which was the version employed by Stroop (1935), participants are presented with a series of cards containing multiple stimuli from one condition only (e.g., incongruent stimuli) and are asked to name the color of the ink of each stimulus without stopping. Cards typically contain from 50 to 100 stimuli. The total time per card is the measure of performance in a given condition. In a variant, the card is presented for a fixed amount of time (e.g., for 45 seconds), and the number of items reported in that time is measured (Golden, 1976).

In 1965, Tecce and Dimartino (1965) employed a different methodology for stimulus presentation (see MacLeod, 1991, for the history of various Stroop methodologies). Since then, many laboratories, interested in timing individual stimuli, have employed the single-trial methodology. In these experiments, participants are presented with a single stimulus in each display (e.g., the word *GREEN* in red ink) and asked to name the ink color of the individual word that appears on the screen (see Figure 2). This allows for a measure of response times to individual trials as opposed to a summation of response time across a large stimulus set. Errors for single words can then be omitted when calculating response-time measures or can be analyzed as variables of interest themselves. Error analysis is not nearly as straightforward in the card version, as Stroop (1935) was well aware. In addition to being able to examine the responses to individual stimuli, this method enables investigators to study both Stroop interference (incongruent RTs minus neutral RTs) and Stroop facilitation (neutral RTs minus congruent RTs). The inclusion of the congruent condition (e.g., the word *GREEN* in green), permitting the measurement of facilitation resulting from color-word agreement, was first described by Dalrymple-Alford and Budayr (1966). The measurement of facilitation using the card version is problematic because when participants are asked to read a whole card of congruent stimuli (e.g., the word *RED* in red ink), it is impossible to ensure that they are not reading the words rather than naming the colors.

Studies of attention commonly use conflict situations in which participants are asked to attend to an object or a dimension and simultaneously ignore other objects or dimensions. The Stroop task produces a robust and reliable effect by creating a conflict between color naming and the habitual response of word reading. Throughout the years, it has become an important task in the study of selective attention. As attentional deficiency is one of the hallmarks of schizophrenia, the Stroop task has been extensively employed in the study of attention failures in patients with schizophrenia.

SCHIZOPHRENIA STROOP STUDIES

Schizophrenia is marked by a variety of symptoms that include, among others, abnormalities of language and attention (Andreasen, 1994). Inadequate language performance in schizophrenia patients has been attributed to attentional deficits reflected in an inability to select the appropriate dimension of the stimulus and to inhibit the irrelevant stimulus (Braff, 1993; Maher, 1983). Because the suppression of the irrelevant word is essential for efficient performance in the Stroop task, this task

has been employed in many studies of attention in the schizophrenia literature. Many researchers have examined the interference component, predicting that it would be increased for schizophrenia patients compared to matched controls. A review of the schizophrenia Stroop studies reveals that this is not necessarily the case and that the variety of methods that have been employed produced inconsistent results. It appears that the form of the task used (card vs. single-trial) as well as other methodological differences contribute to the different patterns of interference exhibited by patients with schizophrenia.

Researchers have described performance on the Stroop task as reflecting selective attention, the functioning of an executive system (i.e., maintaining task set or switching between tasks), the ability to inhibit habitual responses (i.e., reading words), or simply the ability to maintain instructions or set. It is clear that to produce the requested response (name the color of the ink), there is a need to suppress or otherwise overcome the automatic reading of the word. It is possible that although the complexity and convergence of these mental operations are not revealed in studies of normal college students, they may be revealed in the performance of patients. For example, most college students will have no problem in remembering and maintaining the instructions given by the experimenter at the beginning of a Stroop experiment. In contrast, it is possible that certain groups of patients, including those with schizophrenia, may be deficient in maintaining a cognitive set or remembering the instructions and goals necessary to successfully perform the task.

Card Version

The first Schizophrenia Stroop study utilizing the card version was published in 1960. Wapner and Krus (1960) reported a significant interaction between group and condition, but the conditions included in the analysis were not only neutral and incongruent conditions but also word reading. Thus, it is not clear whether the source of this interaction was actually the interference component. In contrast, Abramczyk and colleagues (1983) also used the card version and reported a significant interaction of group (schizophrenia vs. normal controls) by interference condition (neutral vs. incongruent), with patients showing a larger interference effect than normal controls. In a subsequent study, Albus et al. (1996) reported that both first-episode schizophrenia patients and chronic patients with schizophrenia exhibited greater interference than matched controls. A number of other studies using the card version have also reported greater Stroop interference in schizophrenia patients (Brebion, Smith, Gorman, & Amador, 1996; Hanes, Andrewes, Smith, & Pantelis, 1996; McGrath, Scheldt, Welham, & Clair, 1997), although not all have agreed (Purdon, 1998). In the Purdon et al. study, although overall RT slowing was observed in both the color-naming and the word-reading conditions, Stroop interference did not differ between the two groups.

Nopoulos, Flashman, Flaum, Arndt, and Andreasen (1994) examined the effect of practice on Stroop interference and reported that schizophrenia patients showed increased interference at two different testing sessions. Although the schizophrenia patients showed a reduction in Stroop interference from the initial to the subsequent session, their interference was found to be significantly greater than that of normal adults at both testing sessions. Buchanan et al. (1994) reported differences related to symptomatology in the schizophrenia patients tested. Interference was augmented for deficit schizophrenia patients (patients exhibiting strong negative symptomatology) relative to nondeficit schizophrenia patients and normal controls. The nondeficit patients also showed larger interference than normal controls, but this difference did not reach significance.

Other studies (Baxter & Liddle, 1998; Brekke, Raine, Ansel, Lencz, & Bird, 1997; Everett, Laplante, & Thomas, 1989; Golden, 1976; Mahurin, Velligan, & Miller, 1998; McGrath et al., 1997; Verdoux, Magnin, & Bourgeois, 1995; Wapner & Krus, 1960; Wysocki & Sweet, 1985) reported significant differences among the various subject groups in each of the Stroop conditions separately but did not report results of a direct test of the interaction between group and condition. Schwartz and Shagass (1960) reported no difference in interference effects between a group of psychiatric patients and a normal control group. However, their psychiatric group included not only patients with schizophrenia but also patients with personality disorder, who had a somewhat reduced interference effect. This inclusion of two very distinct patient groups could have contributed to a reduction of the interference effect in the psychiatric group as a whole. A survey of the data in the various reports using the card version suggests that in most studies, the effect was in the predicted direction, with the schizophrenia patients showing larger interference effects than normal controls. It is not clear, however, whether the effect could have reached statistical significance in each one of the studies.

In several studies, patient control groups were employed, including brain-damaged patients (Golden, 1976; Wysocki & Sweet, 1985), depressed patients (Everett et al., 1989), and psychiatric patients without a diagnosis of schizophrenia (Schwartz & Shagass, 1960). Only Golden (1976) reported differences between the schizophrenia patients and the nonschizophrenia patient control group. For both neutral and incongruent conditions, the schizophrenia patients were

slower than the normal controls but faster than the brain-damaged patients. There were no significant differences among the three brain-damaged groups (left, right, or diffuse). Schwartz and Shagass (1960) employed young and old "normals" as well as patients with personality disorder, neurosis, schizophrenia, and psychotic depression. They did not test for differences among the various patient groups. Examination of the data from the four groups (i.e., personality disorder, neurosis, schizophrenia, and young controls) suggests that the schizophrenia patients exhibited an interference effect greater than both the young normals and the personality disorder group but comparable to the neurotics.

Summary: Despite somewhat inconsistent results, the majority of data accumulated with the traditional card version of the task, suggest that the card version of the Stroop task produces increased interference in schizophrenia patients.

Single-Trial Version

The first single-trial study to be employed in schizophrenia patients was published in 1969 (Peixotto & Rowe, 1969). In this computerized single-trial version of the Stroop task, Peixotto and Rowe (1969) presented single Stroop stimuli on a computer screen and the schizophrenia subjects were asked to name the ink color into a microphone that was interfaced to the computer. This methodological approach, which was first introduced by Tecce and DeMartino (1965), allowed the investigators to time the responses in milliseconds and to exclude individual error trials from the analysis. In addition, it allowed for the presentation of congruent stimuli, which, in turn, yielded measures of facilitation. In a number of single-trial Stroop studies (Barch, Carter, Hachten, Usher, & Cohen, 1999; Carter, Robertson, & Nordahl, 1992; Chen, Wong, Chen, & Au, 2001; Henik et al., 2002; Perlstein, Carter, Barch, & Baird, 1998; Taylor, Kornblum, & Tandon, 1996), schizophrenia patients showed augmented facilitation relative to normal controls but no difference in RT interference. Similar findings of equivalent Stroop RT interference have also been reported in several Stroop priming experiments (Laplante, Everett, & Thomas, 1992; Salo, Henik, Nordahl, & Robertson, 2002a, 2002b; Salo, Robertson, & Nordahl, 1996; Salo, Robertson, Nordahl, & Kraft, 1997) and neuroimaging studies (Carter, Mintun, Nichols, & Cohen, 1997; Nordahl et al., 2001). Carter, Robertson, Nordahl, O'Shora-Celaya, and Chaderjian (1993) found augmented facilitation to be characteristic of the undifferentiated subtype of the disorder, whereas patients of the paranoid subtype exhibited increased interference and normal facilitation. This is an intriguing conclusion, the generalizability of which remains to be demonstrated.

As suggested above, the majority of single-trial Stroop studies with schizophrenia patients have reported equivalent Stroop RT interference. Several single-trial Stroop studies have also noted increased incongruent errors in patients with schizophrenia. Barch and colleagues (Barch, Carter, Hachten, et al., 1999; Barch, Carter, Perlstein, et al., 1999) reported equivalent RT interference between 56 schizophrenia inpatients and 25 healthy controls, but they found greater errors in the incongruent condition in the schizophrenia group. This finding of increased error rates in the incongruent condition has since been replicated in other studies (Carter et al., 1997; Cohen, Barch, Carter, & Servan-Schreiber, 1999; Nordahl et al., 2001; Perlstein et al., 1998) with significant correlations reported between incongruent error rates and facilitation (Barch, Carter, Hachten, et al., 1999). A preliminary observation reveals that those studies reporting increased error rates in schizophrenia patients all employed either long intertrial intervals (ITIs) or long response stimulus intervals (RSIs) (i.e., more than 2,000 ms). The RSI is the time from the onset of the vocal response to the onset of the next trial, and the ITI is the fixed time duration between trials. In contrast, those studies that did not detect increased incongruent errors in schizophrenia patients employed ITIs or RSIs of less than 1 second.

A recent study by Salo and colleagues (2002b) directly examined the effect of RSI on Stroop interference and facilitation in schizophrenia patients. They found that the schizophrenia patients exhibited a pattern of slowed reaction times to the incongruent stimuli at the long RSI (2,000 ms) compared to the short RSI (500 ms).[1] In contrast, the reaction times of control subjects to incongruent stimuli actually decreased as the RSI increased, resulting in reduced interference. Schizophrenia patients also exhibited increased errors at the longer RSI compared to controls. Whereas the incongruent error rates of the control subjects decreased significantly at the longer RSI (2,000 ms), the incongruent error rate remained constant across long and short RSIs for the schizophrenia patients. This pattern of results suggests that although control subjects took advantage of the extra time between trials to focus their attention on the relevant stimulus dimension, resulting in faster response times, the schizophrenia patients may have become more distracted as the time interval between trials was extended. The long ITI or RSI might produce lapses in the patients' maintenance of task instructions such that they may switch to reading the irrelevant word instead of focusing on the word's color as the task requires.

A similar proposal was put forth by Brown and Marsden (1988) in a study of Parkinson's disease (PD)

patients. In this study, a variation of the single-trial version was used in which participants were asked to either read the word and ignore the color in one block of trials or name the color and ignore the word in a separate block. In addition, under one condition, the relevant stimulus attribute was cued before each trial, and under another condition, the relevant attribute was cued only at the beginning of the block. In the latter described condition, participants had to remember which attribute was currently relevant. Compared with the control group, PD patients exhibited enhanced Stroop interference in the uncued condition, which required maintenance in memory of task instructions, but did not differ from the control participants in the cued condition.

Summary: Schizophrenia patients show increased facilitation relative to normal controls on the single-trial version of the Stroop task, with interference comparable to normal controls. However, when the intertrial interval is relatively long, some single-trial studies have reported increased Stroop error rates (Perlstein et al., 1998), whereas others have reported increased Stroop RT interference (Hepp, Maier, Hermle, & Spitzer, 1996) or both increased errors and increased RT interference (Salo et al., 2002b). In contrast to the effects of RSI on interference effects and error rates, the length of the RSI had no effect on the facilitatory component of the Stroop effect.

Thus, the finding that schizophrenia patients show interference that is comparable to normal controls on the single-trial version of the Stroop task stands in contrast to the augmented interference, which is observed on the card version of the task. This suggests that the Stroop task is not unitary in terms of cognitive requirements; different versions of the task require diverse cognitive operations.

Card Versus Single-Trial

Several studies have directly compared Stroop effects in normal controls and schizophrenia patients on the two versions of the Stroop test. In two separate studies of inpatients and outpatients (Hepp et al., 1996; Perlstein et al., 1998), no significant difference in Stroop interference using the card version was reported. Perlstein et al. (1998) reported that schizophrenia patients actually exhibited reduced Stroop interference in a card version of the Stroop task compared to controls, with equivalent Stroop interference emerging on the single-trial version. Hepp et al. (1996) reported increased interference in patients with schizophrenia using the single-trial version of the Stroop task but not when using the card version. It should be noted, however, that only a small number of schizophrenia patients were tested in the Hepp et al. study, and many errors were committed. Moreover, long RSIs were employed (> 2,000 ms) in both the Hepp et al. and the Perlstein et al. studies, which could have contributed to the increased interference in the schizophrenia patients when the single-trial version was employed (Salo et al., 2002b).

Students of the effects of distractors (Baylis & Driver, 1992; Eriksen & Eriksen, 1974) and investigators of the Stroop effect (Boucart, Mobarek, Cuervo, & Danion, 1999; Schadler & Thissen, 1981) have suggested that the card version of the task may augment interference because of the existence of many irrelevant items around the target item at a given time. Boucart et al. (1999) directly compared the performance of 12 schizophrenia patients and 12 controls on the two Stroop versions and found increased interference only on the card version. Boucart et al. then presented three intermediate single-trial tasks that tested the effects of distractors in the spatial environment of the target. They found that the presence of a distractor in the spatial surround slowed the reaction time of the schizophrenia patients compared to the controls. Boucart et al. suggested that one of the sources of increased card Stroop interference might be the inability to ignore distractors surrounding the target rather than the inability to ignore the irrelevant (word) dimension.

Suppose that the interference in the single-trial version of the Stroop task is primarily the result of the within-item interference. Then, the augmented interference presented by schizophrenia patients under the card, but not the single-trial, version of the task suggests that schizophrenia patients have the ability to suppress within-item interference. In contrast, they are deficient in handling the between-item interference (the second source of interference) and are unable to suppress intrusions of items that surround the item currently in focus. This hypothesis fits with the idea that increased Stroop interference exhibited by schizophrenia patients in the card version reflects the inability to narrow down attention on one object amidst a cluttered array (Boucart et al., 1999). This increased interference produced in the card version of the Stroop task may be the result of factors extraneous to the target Stroop stimulus (Baxter & Liddle, 1998; Boucart et al., 1999; Chen et al., 2001). Another possibility is that the discrepancy in results may be the result of a difference in effect size. That is, interference generated by the above-mentioned sources is the result of one and the same mechanism. Because under the card version of the task there are more aspects of the irrelevant stimulus that drive this mechanism, this version produces a much larger effect.

It is relatively easy to envision such a mechanism if one considers attention as a limited pool of resources (Kahneman, 1973) that needs to be shared by all mental operations carried out at a given point of time. The two versions of the Stroop task share the existence of an irrelevant word that carries the relevant, to-be-named color. However, the card version contains additional irrelevant

features that may affect focusing on a single item—(a) the item that is in focus at a given time is surrounded by other items creating a cluttered field; (b) the items are displayed in close spatial proximity to each other, and thus, their spatial arrangement may influence the ability to focus attention; (c) the sequential color distribution of the items on the card may influence or prime each other; and (d) the card version requires the subject to shift attention from one item to another to keep track of stimuli that were already scanned and focus on new stimuli yet to be scanned. All of these features can affect the ability to focus attention on a given item, as well as on the ability to share a limited pool of resources. Any one of these additional task requirements inherent to the card version of the Stroop task is robbing the relevant task dimension of the limited resources necessary to process it. Hence, it is possible that the same attentional resources are required for the single-trial and the card versions of the task, but the card version requires that these resources be distributed across a larger pool of recipients (i.e., task demands). This would imply that an inability to efficiently allocate attentional resources might account for group differences when the card version of the Stroop task is used.

Summary: The augmented interference exhibited by the patients under the card but not the single-trial version of the task suggests that schizophrenia patients have the ability to suppress within-item interference. In contrast, they are deficient when additional attentional requirements are put forward. More research is required to clarify whether this deficiency is because of overtaxing the same mechanism or a damage of a different attention mechanism (e.g., narrowing down of the attention field).

Methodological Issues

There are a number of potentially important differences between the single-trial and the card version of the Stroop task, differences that may obscure the underlying mechanisms contributing to attentional deficits in schizophrenia patients (MacLeod, 1991; Salo et al., 2001). In the standard card version of the Stroop task, the conditions are blocked, whereas in the single-trial Stroop version, the conditions are randomly mixed within each block. In the card version, the subject must not only respond to and name the ink color of the attended stimulus but also ignore the adjacent irrelevant flanker words and colors. In contrast, the single-trial Stroop version typically presents the stimulus at central fixation and does not require the subject to generate eye movements or to move attention down columns of stimuli. The single-trial version most often includes congruent trials as well as the other two conditions. Some authors suggested that this may bias the subject toward reading the words (MacLeod & MacDonald, 2000). Studies using the single-trial version sometimes use manual responding (e.g., Laplante et al., 1992; MacLeod, 1991). Studies with normals showed that switching from vocal responding to manual responding reduces the effect (Keele, 1972; MacLeod, 1991).

The inclusion of error responses and corrections in the reaction time sum of the card Stroop version is another major difference that could affect test results in schizophrenia patients. It should also be noted that many of the studies that have reported increased Stroop interference in schizophrenia patients have only reported performance in the incongruent condition without calculating an "interference" or "cost" relative to a baseline condition. It seems that when researchers use only the incongruent condition of the task (McCormick et al., 1980; Porterfield & Golding, 1985), it is not clear what aspect of schizophrenia performance they are probing. RT studies suggest that the incongruent condition measures both general performance (e.g., general RT slowing associated with schizophrenia) as well as specific attentional deficits. Thus, one should employ a baseline or control condition to accurately probe the targeted aspect of performance.

Facilitation Versus Interference in the Single-Trial Version

Several studies have suggested dissociation between the interference and the facilitation components of the Stroop effect (Henik, Singh, Beckley, & Rafal, 1993; Lindsay & Jacoby, 1994; MacLeod, 1991; MacLeod & MacDonald, 2000; Tzelgov, Henik, & Berger, 1992). Accordingly, data from several single-trial studies (Carter et al., 1992; Henik et al., 2002; Taylor et al., 1996) suggested that schizophrenia patients showed augmented facilitation relative to normal controls, whereas the interference did not differ between groups. The facilitatory component may involve processes that are less subject to strategic control and occur prior to or at the stage of lexical entry. For example, when the proportion of neutral trials is reduced, there is a reduction in interference (Tzelgov et al., 1992). This effect is related to subjects' expectation as to the nature of the upcoming trial and the need to introduce suppression of the irrelevant dimension. Neutral proportion affects interference but not facilitation, and the same is true for congruent proportion that affects interference but not facilitation (MacLeod, 1991). If facilitation was the result of processes operating postlexically (after the word was recognized), it should be influenced by neutral proportion in the same way that the interference component is. Another possibility was suggested by MacLeod and MacDonald (2000). He suggested that facilitation results from reading errors; that is, the subject occasionally

reads the irrelevant words rather than naming the relevant colors. For example, suppose that the word *BLUE* is presented in the color blue. The participant reads the word and responds "blue." This is obviously a response error (responding to the word rather than to the color), but it cannot be detected by the experimenter, because it does not differ from the correct naming response that is also "blue." As reading the color words is faster than naming the color, these errors speed up responding and produce the facilitation effect. This, in turn, creates the dissociation between facilitation and interference. Note that this suggestion argues that facilitation may be more subject to strategy, the opposite of the above-mentioned argument (Tzelgov et al., 1992).

In a recent study (Henik et al., 2002), it was reported that schizophrenia patients were able to exploit the neutral proportion information in such a way that they exhibited reduced interference for small proportions of neutral trials. They did, however, exhibit a much larger facilitation effect than normal controls. Eyeballing the data of Henik et al. (2002) suggests that differences between the control subjects and the schizophrenia patients are smaller in the congruent condition than in the other two conditions; that is, the patients' response times to the congruent stimuli are closer to the controls' congruent condition than the response times in the other two conditions (neutral and incongruent). Hence, it seems that facilitation is produced by a relative change in the congruent condition. In the first single-trial study to report augmented facilitation in schizophrenia patients, it was suggested that the observed abnormal facilitation might be peculiar to the single-trial version of the task and may represent an abnormal spread of activation within semantic memory (Carter et al., 1992). Later studies, which examined the facilitation effect in more detail, proposed that the mechanism underlying abnormal Stroop facilitation in schizophrenia patients reflected a "disturbance in the strategic allocation of attention" (Barch, Carter, Perlstein, et al., 1999). Furthermore, Barch et al. suggested that the failure of allocating attention to the relevant dimension may also be reflected in the increased rate of incongruent errors exhibited by the schizophrenia patients (Barch, Carter, Hachten, et al., 1999; Barch, Carter, Perlstein, et al., 1999).

MacLeod (1991) has suggested that although the interference component of the Stroop effect is robust and reliable, the facilitation is usually small and, in many cases, nonsignificant. He also notes that part of the reason may be a measurement problem, in that facilitation must speed up an already fast response, a kind of performance "floor." In some cases, facilitation may simply represent the fact that subjects are reading the word instead of naming the color, and thus, RTs to congruent word types are significantly reduced (MacLeod, 1996; MacLeod & MacDonald, 2000). As suggested earlier, because errors on congruent trials would be coded as correct responses, it is not possible to accurately determine what the subjects are actually doing.

Summary: Many single-trial studies have reported augmented facilitation and interference comparable to controls. However, there is a disagreement with respect to the source of this effect. Early studies suggested that increased facilitation was the result of lexical or prelexical processes, whereas subsequent studies proposed that word-reading errors or disturbance in allocating attention are involved in producing the augmented facilitation. This subject is an issue of debate and more experiments are needed to resolve this issue.

VARIANTS OF THE STROOP TASK

Some studies (Klein, 1964; Langer & Rosenberg, 1966) have employed color-related words or symbols to generate the Stroop effect, and these same stimuli have also been employed with schizophrenia patients (Langer, Stein, & Rosenberg, 1969; Nehemkis & Lewinsohn, 1972; Peixotto & Rowe, 1969). Using the card version, Klein (1964) employed color-related words (e.g., lemon, grass) in healthy control subjects and found that they created more interference than noncolor words but less interference than color words (see also Dalrymple-Alford, 1972, for analogous results using the single-item version). Langer and Rosenberg (1966) created a phonetic version of the Stroop task and found that subjects associated certain phonetic symbols with specific colors (e.g., *zah* with red and *tur* with green). Thus, these phonetic symbols could be employed to create a congruent condition (e.g., *zah* in red and *tur* in green) or an incongruent condition (e.g., *zah* in green and *tur* in red). Subjects were slower to name the color under the phonetically induced incongruent condition than the phonetic congruent condition. Langer, Stein, and Rosenberg (1969) employed this phonetic version of the Stroop task with schizophrenia patients and found that compared to normal controls, the patients exhibited a significantly larger Stroop effect with the phonetic stimuli. Note that this study employed the card version of the task and no neutral condition was included so that the overall Stroop congruency effect, rather than the separate components of interference and facilitation, was studied. In addition, it is worth mentioning that the use of nonwords enabled the investigators to use a congruent condition and not worry about the subjects reverting to word reading, which can be a potential problem with the card version of the task.

In another variation of the Stroop task, a pair of studies (David, 1993; Woodruff et al., 1997) separated the two dimensions of the stimuli by presenting a vertical color strip alongside a vertical color word printed in black. This technique goes back to Dyer (1973) in which he separated word and color to study laterality effects. Stimuli were presented to the left or the right visual field (unilateral condition) or at the center, in which case one dimension was presented to the right of the center and the other to the left (bilateral condition). David (1993) employed only congruent and incongruent stimuli (i.e., no neutral condition) and computed the congruency effect—a difference between these two conditions. Exposure duration was short (120 ms). Subjects were schizophrenia patients, affective patients, and normal controls. There was no difference in the congruency effect among the groups for the unilateral presentations, but in the bilateral presentations, a clear difference emerged between the groups, with the schizophrenia patients presenting a larger congruency effect than the other two groups. David interpreted this increased Stroop effect as a failure of the schizophrenia patients to regulate interhemispheric transmission (i.e., functional hyperconnection).

In a subsequent study, Phillips, Woodruff, and David (1996) tested a group of 27 schizophrenia patients using the same lateralized Stroop design employed by David (1993). In the modified Stroop task employed by Phillips et al., a neutral condition was also employed so that the congruency effect as well as interference and facilitation could be measured. They found that the congruency effect did not differ between schizophrenia patients and controls. Further analyses revealed, however, that interference effects were reduced in the schizophrenia patients when the stimuli were presented bilaterally but did not differ between the groups when the stimuli were presented unilaterally (right or left visual field presentation). Phillips et al. (1996) suggested that the reduced interference in the bilateral presentation might have resulted from abnormal callosal function in the schizophrenia patients. Although the studies reported above (David, 1993; Phillips et al., 1996) differed in how Stroop effects were measured (congruency vs. interference), both studies interpreted their findings in the schizophrenia patients as reflecting abnormal callosal function.

Peixotto and Rowe (1969) employed a mixed version of the task by implementing features from both the card and the single-trial version of the Stroop task. Similar to the single-trial version, subjects were presented with a single stimulus (e.g., the word *GREEN* in red ink) on each trial, but like the card version, Stroop conditions were blocked by word type (i.e., neutral, incongruent). Their participants were schizophrenia patients, psychoneurotics, and normal controls. In addition to the three Stroop conditions (reading, naming color patches, naming incongruent color words), there was one more incongruent condition of color associates (e.g., the word *GRASS* in red ink; see Klein, 1964). The authors reported no overall difference among groups for reading or naming color patches (i.e., neutral condition) but did report significant differences among groups for the two incongruent conditions. Additional analyses on mean latencies adjusted for age and IQ showed that schizophrenia patients were slower than the other two groups under the two incongruent conditions, whereas there was no difference between the two control groups. Because the groups differed on the incongruent conditions but not on the neutral condition, the authors concluded that the schizophrenia patients showed a larger interference than the other two groups of subjects.

Other studies have manipulated temporal distance between the features of the Stroop stimulus (i.e., word form vs. color) by manipulating the time interval or stimulus onset asynchrony (SOA) between the appearance of the ink color and the word stimulus (Laplante et al., 1992; Schooler, Neumann, Caplan, & Roberts, 1997). This technique goes back to Dyer (1971) and was thoroughly explored in normal subjects by Glaser and Glaser (1982). In the study by Laplante et al. (1992), the SOA was varied across blocks of trials such that on some trials, the word would first appear in black for varying periods of time (450 ms to 900 ms) prior to appearing tinted in the appropriate color. No difference in Stroop effects emerged between the schizophrenia patients and controls across conditions. Moreover, similar to Peixotto and Rowe (1969), Laplante and colleagues (1992) blocked the various word types but did not replicate the increase in interference in the schizophrenia patients as reported by Peixotto and Rowe. Another study by Schooler et al. (1997) investigated 59 schizophrenia patients (41 inpatients and 18 outpatients). This study randomly mixed nine SOAs within blocks of trials. In this particular study, SOA was manipulated in both directions, with the color hue appearing first on some trial sequences and the word printed in black appearing first on others. Although the controls showed marginally less interference than the schizophrenia subjects collapsed across all SOAs, this difference did not reach statistical significance. Additional analyses revealed that the schizophrenia patients displayed a different pattern of reaction time interference across SOAs, with peaks of interference occurring at earlier SOAs in schizophrenia patients compared to controls, which the authors interpreted as reflecting slowed processing.

Schizophrenia patients showed an enlarged congruency effect (Langer et al., 1969) that might be the result

of increased interference as shown by several studies that used the card version of the task. Blocking of word types (i.e., incongruent, neutral) produced mixed results—that is, enlarged interference in one study (Peixotto & Rowe, 1969) and interference comparable to normals in another study (Laplante et al., 1992). Lateralization studies showed that unilateral presentations of Stroop stimuli produced similar results in patients and controls, whereas bilateral presentations of Stroop dimensions (i.e., color and word) did not produce consistent results. Separation of the Stroop dimensions over time did not produce differences in Stroop interference between patients and controls, although the peaks of interference appeared earlier for the patients than for the controls (Schooler et al., 1997). The studies reviewed in this section point to various aspects of the Stroop task that need to be considered and possibly further investigated. It is possible that separation in time or space of the stimulus dimensions may produce interesting differences between studied populations. Note, however, that such changes in the basic paradigm might not only reveal interesting differences between populations but may also introduce factors not manipulated within the common versions of the task. For example, presenting the word ahead of the color gives the word an advantage that could affect a patient population to a much larger degree than a normal population.

Summary: Variants of the Stroop task point to additional aspects of cognitive performance that need to be considered. For example, the separation in time or space of stimulus dimensions may produce differences between studied populations. However, their relationship to the two major versions of the task (card or single-trial) or to conclusions drawn from the use of these versions should be considered cautiously.

NEGATIVE PRIMING (NP) AND STROOP EFFECTS

A number of schizophrenia studies have examined the persistence of Stroop effects using Stroop stimuli in negative priming (NP) paradigms (Beech, Baylis, Smithson, & Claridge, 1989; David, 1993; Laplante et al., 1992; Moritz et al., 2001; Salo et al., 2002a, 2002b; Salo et al., 1996; Salo et al., 1997). Stroop negative priming is a slowed reaction time or increased error rate that occurs when the irrelevant aspect of the stimulus on trial $n - 1$ (color name) is the same as the relevant aspect of the stimulus on the next trial n (ink color), a result first reported by Dalrymple-Alford and Budayr (1966) and, subsequently, extensively investigated by others (e.g., Lowe, 1979, 1985; Neill, 1977; Neill & Westberry, 1987; Tipper, 1985; Tipper & Driver, 1988). An example of an NP sequence using Stroop stimuli appears in Figure 2. The first trial presents the word *RED* in blue ink and this trial is followed by a trial with the word *GREEN* printed in red ink. In most studies with schizophrenia patients it was assumed that (a) to suppress habitual reading, participants inhibit the irrelevant word and (b) that this inhibition lingers to the following trial. As a result, naming the red ink of *GREEN* would be slowed down because of the previous inhibition of the irrelevant *RED*. The last two trials in the sequence depict two unrelated trials. NP is examined by comparing responding to related (trial 2) and unrelated (last trial) trials. NP is indicated by slower responding to related than to unrelated trials; that is, in both cases, the response is *red*, but the latency of responding is slower in trials like the second trial than in trials similar to the last trial.

Several studies have reported reduced Stroop NP in schizophrenia patients but did not test within-trial Stroop effects (Beech et al., 1989; Moritz et al., 2001). In contrast, a study carried out by Laplante et al. (1992) was specifically designed to examine reductions in NP in schizophrenia patients together with Stroop effects. In the context of reduced NP, Laplante et al. observed equivalent Stroop interference in the schizophrenia patients and the controls. However, one should note, as discussed above, that both RSI (i.e., the time interval between the subject's response and the onset of the next stimulus) and the SOA were manipulated in this study. SOA was varied by having the lexical distractor displayed in black 450 ms or 900 ms prior to appearing tinted in the appropriate color. The condition most similar to the Peixotto and Rowe study (1969) was the zero-SOA condition, which did not give rise to a difference in interference between the schizophrenia patients and the control subjects. Laplante et al. (1992) employed manual responding, which could have contributed to a general reduction in the Stroop effect. Otherwise, the general setup would appear to have been favorable for getting a Stroop effect. On most trials, subjects had to wait for the black word to change into a color word, which should have augmented the Stroop effect (Glaser & Glaser, 1982; Sugg & McDonald, 1994).

Salo and her colleagues (Salo et al., 1996, 1997, 2002a, 2002b) also studied NP and Stroop interference in schizophrenia patients compared to normal controls. They found no significant difference in either interference or facilitation between patients and controls across studies, although the facilitation effect of the patients in one study (Salo et al., 1996) was twice as large as that presented by normal controls. In the presence of normal Stroop interference, Salo et al. (1997) reported reduced NP in a group of unmedicated schizophrenia patients that returned to normal priming levels once medication therapy was resumed (Salo et al., 1997). In contrast, no change in Stroop interference or Stroop facilitation was

observed following the restoration of medication therapy. Thus, medication appears to have a more selective effect on attentional processes that are sustained over time in schizophrenia patients than on immediate selective attention.

Summary: Schizophrenia research using Stroop stimuli in NP tasks supports the following hypotheses: (a) the processes underlying within-trial Stroop effects (i.e., interference and facilitation) and between-trial NP may be mediated by separate mechanisms, (b) NP effects in schizophrenia appear to be vulnerable to medication therapy, and (c) Stroop interference and facilitation appear more stable than priming effects and less vulnerable to change.

INTERMEDIATE SUMMARY

A summary of the findings to this point suggests that when the card version of the Stroop task is employed, augmented interference effects are reported in many schizophrenia studies, although not all. In contrast, most of the studies that employed the single-trial Stroop task in schizophrenia patients reported augmented facilitation, with interference comparable to controls. The single-trial studies that did report increased Stroop RT or error interference in patients with schizophrenia (Hepp et al., 1996; Nordahl et al., 2001; Perlstein et al., 1998) employed long intertrial intervals or reported data from certain subtypes of schizophrenia patients (i.e., paranoid patients) (Carter et al., 1993). The latter issue will be discussed in greater detail in the following section. Studies that employed nonschizophrenia psychiatric controls could reveal whether augmented interference is unique to schizophrenia. Unfortunately, the results are mixed. Two studies (Everett et al., 1989; Schwartz & Shagass, 1960) indicated no difference, and one study (Peixotto & Rowe, 1969) reported a significant difference between the schizophrenia patients and the psychiatric controls. Thus, it is possible that the interference found under the card version of the task was shared by various patient groups and may not be unique to schizophrenia. Although increased facilitation has been reported across many schizophrenia studies, it has also been reported in Parkinson's disease (Henik et al., 1993) and thus may be related to disturbances of the dopamine system and may not be unique to schizophrenia. Earlier, we pointed out that the interference in the card version may reflect an inability to narrow down attention on one object amidst a cluttered array or a deficiency in using the limited pool of attentional resources. In contrast, augmented facilitation, indicated by performance in the single-trial version of the task, suggests a different aspect of selective attention deficiency. The increase in facilitation could be the result of an early, nonstrategic priming effect or to a deficiency in the strategic allocation of attention that may result in word-reading errors. Whether the same or different mechanisms are indicated by the increased interference and facilitation, it seems that these effects point to deficiencies in selective attention that are not necessarily unique to schizophrenia because they are shared by other patient populations.

SYMPTOMATOLOGY AND STROOP EFFECTS

A small group of studies have examined the relation between Stroop effects and schizophrenia symptomatology. Liddle and Morris (1991), using an abbreviated form of the card version, found that the performance of schizophrenia patients in the incongruent Stroop condition correlated with psychomotor poverty (e.g., poverty of speech, lack of spontaneous movement, blunting of affect) as well as disorganization (e.g., inappropriate affect and thought disturbance). The first correlation could be explained by general slowness and hesitation in vocal production as this correlation shrank to an insignificant level when the measure of reading color words in black was partialled out. In contrast, partialling out this same measure from the correlation between naming incongruent color names and disorganization did not change the correlation or its significance. Liddle, Friston, Frith, and Frackowiak (1992) also tested regional cerebral blood flow (rCBF) for differences between schizophrenics and normals while performing various neuropsychological tasks. They suggested that the right anterior cingulate gyrus showed maximal rCBF during performance of the Stroop task and may be associated with the disorganization syndrome. This will be discussed further when we discuss imaging studies of the Stroop effect.

Using a card version of the Stroop task, Buchanan et al. (1994) reported augmented interference for deficit schizophrenia patients (patients exhibiting strong negative symptomatology) relative to nondeficit schizophrenia patients and normal controls. Although the nondeficit patients exhibited larger interference than controls, this difference did not reach significance. Moritz et al. (2001) also found a relation between increased Stroop interference on the card version and the disorganization syndrome. In contrast, Penn, Hope, Spaulding, and Kucera (1994) employed the card version of the task in a study of social anxiety in schizophrenia and found that negative and positive symptoms were related to different measures of anxiety but not to Stroop measurements.

Summary: At present, it seems that additional research is needed before a clear picture emerges of the relation between schizophrenia symptomatology and the Stroop effect.

MEDICATION EFFECTS

Schizophrenia Studies

Four studies using the single-trial Stroop version examined the effects of prescribed neuroleptic medication on Stroop effects in patients with schizophrenia (Chen et al., 2001; David, 1993; Henik et al., 2002; Salo et al., 1997). In a recent large-scale study conducted with 56 first-episode schizophrenia patients, Chen et al. (2001) reported that consistent with other single-trial Stroop studies, neuroleptic medication did not modulate Stroop interference. In contrast, medication seemed to produce an increase in facilitation that was normalized with sustained medication treatment. In the Salo et al. (1997) study, schizophrenia patients who had been washed off neuroleptic medication for a 2-week period were tested both during the washout period and again after they had resumed medication therapy. The restoration of medication therapy had no effect on Stroop interference or facilitation. David (1993) reported similar findings. Henik et al. (2002) also employed the single-trial Stroop version in a group of schizophrenia patients enrolled in an investigational drug study and found that medication did not modulate Stroop effects.

In contrast, using the card version, Mirsky et al. (1984)[2] compared schizophrenia patients off and on medication and found that interference in three of the subjects was elevated when they were taken off medication, whereas Stroop interference was actually reduced in one unmedicated patient. However, in the study by Mirsky et al., no statistical tests were presented, which makes it difficult to interpret the results. Killian, Holzman, Davis, and Gibbons (1984) also examined the effects of antipsychotic drugs on Stroop performance using the card version in schizophrenia and depressed patients. Their findings are limited as they defined Stroop interference as the difference between reading color words in black and naming neutral stimuli, which is not an appropriate measure of Stroop interference.

Classen and Laux (1989) employed the card version of the Stroop task to compare the effects of haloperidol (a traditional dopamine blocker) and remoxipride (a dopamine receptor blocker having a selective affinity to D2-receptors) on attention. They treated 29 schizophrenia patients for 28 days and found that haloperidol reduced interference, but remoxipride had no effect on Stroop interference. Serafetinides, Collins, and Clark (1972) also treated chronic schizophrenia patients with haloperidol, clopenthixol, and chlorpromazine for 12 weeks. Compared with the placebo, all drugs were found to be effective antipsychotic agents; however, no drug had any effect on Stroop interference.

Several studies have examined the effects of drugs other than neuroleptics on Stroop performance in schizophrenia patients (Cassady, Thaker, Moran, Birt, & Tamminga, 1992; Rosse et al., 1992; Serafetinides & Clark, 1971; Wapner & Krus, 1960). Cassady et al. (1992) tested the effects of a GABA agonist, muscimol, on Stroop performance, tardive dyskenisia, and saccadic distractibility in 10 schizophrenia patients. GABA is a major inhibitory neurotransmitter in the basal ganglia and plays a major role in motor function throughout the brain. GABA-mimetic drugs often improve tardive dyskinesia (TD), an involuntary movement condition that can occur as a side effect of chronic neuroleptic treatment. Cassady et al. proposed that the administration of muscimol, a GABA agonist, should improve both TD and Stroop performance of schizophrenia patients with TD. They tested each patient on muscimol and placebo but found no effect on either TD or Stroop performance. However, a significant correlation emerged between changes in saccadic distractibility and Stroop interference scores. As oculomotor distractibility improved with muscimol, Stroop interference worsened. Accordingly, the authors suggested that performance on the Stroop task may not be mediated through the same motor pathways in the anterior cingulate circuit linked to motor and oculomotor abnormalities or may not be disrupted in TD.

Rosse and colleagues (1992) placed schizophrenia patients on a tryptophan (TRP)-deficient diet to reduce serotonorgic neural transmission. L-TRP is the amino acid precursor of serotonin, and thus, a diet deficient in tryptophan reduces the serotonin levels in the system. Participants were tested before, during, and after the diet. For the neutral condition, there was a significant difference between the prediet and the diet phase but no difference between the prediet and postdiet phases. In contrast, the diet improved performance on the incongruent condition relative to the prediet case, and this persisted into the postdiet phase. Unfortunately, practice is confounded in this study, and it is not easy to tell whether practice was a major factor in this improvement. Serafetinides and Clark (1971) investigated the effect of tybamate, a minor tranquilizer, as maintenance therapy and for relief of anxiety and tension during phenothiazine withdrawal. Chronic schizophrenia patients were studied in a double-blind placebo-controlled experiment and no effect of tybamate was found.

Nonschizophrenia Studies

Several drug studies were carried out with nonschizophrenia patients and with normal volunteers. Such studies could help interpret the schizophrenia drug studies and to help decide whether any reported effects in the latter studies are unique to schizophrenia.

Berger et al. (1989) studied the effects of haloperidol in patients suffering from idiopathic spasmodic torticollis, a condition characterized by involuntary posturing of the head away from its normal central position and linked to functional disturbances within the dopaminergic rich basal ganglia region. These patients were asked to stop taking their medication 3 months prior to the study. Neuropsychological tests were administered twice with a 3-week interval between pretest and posttest. Three days before the posttest, patients were treated with 60 mg haloperidol decanoate. There were no differences in card Stroop interference between the two groups at any point. Hartley and Couper-Smartt (1978) employed normal subjects to study the effects of chlorpromazine, a dopamine blocker, on attention. Comparisons of different doses of chlorpromazine (25 mg or 75 ms to 68 kg body weight) and placebo gave rise to no significant difference in the Stroop effect.

Another study (Jones, Allen, Griffiths, Marshall, & Richens, 1986) investigated the effects of binedaline, a medication with properties similar to tricyclic antidepressant medication, on Stroop effects in normal volunteers and found no medication effect. In yet another study, Nakano, Gillespie, and Hollister (1978) studied the effects of antianxiety drugs on experimentally induced stress. They recruited young, normal subjects with high levels of trait anxiety, produced stress by an experimental task (the mirror drawing test) and gave single doses of diazepam (5 mg), nabilone (2 mg), or placebo to separate groups of subjects. They found no effect of drug on Stroop interference in spite of the fact that the drugs seemed to have an effect on the mirror-drawing test. Boulenger et al. (1989) also found no effects of diazepam on Stroop interference. They tested 12 young, healthy volunteers, all women, with single doses (10 mg) of diazepam, buspirone (a nonbenzodiazepine that lacks anticonvulsant and muscle-relaxant properties and interacts minimally with CNS depressants), and placebo. Drugs were administered to individual subjects in random orders at 1- or 2-week intervals between administrations. Neither drug seemed to have an effect on Stroop interference. Griffiths, Jones, and Richens (1986) studied effects of three benzodiazepines (flurazepam, lormetazepam, and triazolam) and one nonbenzodiazepine, zopiclone. The four drugs and a placebo were administered in a random order, with 7-day intervals between drugs, to 10 young, male volunteers. Subjects were tested several times after each drug ingestion (0, 1, 4, or 10 hours). The authors computed an unusual measure of interference, which was the difference between the incongruent and the neutral conditions divided by time to read color names in black. They found a significant interaction between time after drug ingestion and drug type but noted that "despite this interaction being significant there were no significant differences between any of the treatments and placebo" (p. 652).

Of the 12 studies that examined the effect of medication in schizophrenia patients, only two (Classen & Laux, 1989; Rosse et al., 1992) reported significant effects of drugs on Stroop interference. The effect in one of these studies (Rosse et al., 1992) may be a result of practice rather than a medication effect. The effect of haloperidol found in the other study (Classen & Laux, 1989) was not replicated in another study that also used haloperidol (Serafetinides et al., 1972). A number of factors (e.g., methodology, type of patients) could explain the discrepancy in the results.

Summary: Of the five studies that examined medication effects in nonschizophrenia patients and healthy controls, none reported an effect of medication on Stroop interference. Most of these studies employed the card version of the Stroop task, but it seems that three of the single-trial studies do not change our summary statement. Note, however, that Chen et al. (2001) suggested that medication could produce an increase in facilitation in first-episode patients. Hence, although it is reasonable to conclude that medication does not modulate the interference component of the Stroop effect, it is also possible that medication might affect the facilitatory component.

It is interesting to note that there is some evidence that neuroleptic medication can increase inhibition of distractors in some cognitive tasks (Gray, Feldon, Rawlins, Hemsley, & Smith, 1991), can reinstate negative priming in schizophrenia patients (Salo et al., 1997), and can increase negative priming in controls (Beech et al., 1989). Thus, one possibility is that the mechanisms generating the Stroop effect are not prone to the same influence of medication as other attentional mechanisms.

GENERALIZED SLOWING OR ATTENTIONAL DEFICIT

Schizophrenia patients are usually slower than normal controls, so one may question whether findings of augmented Stroop effects in schizophrenia are because of general slowing or a specific process that occurs in addition to the general slowing. Abramczyk et al. (1983) examined this issue by computing the ratio of incongruent to neutral to show the proportional increase associated with incongruent stimuli. The analysis of the original data produced a significant interaction of group

(schizophrenia patients vs. normal controls) by interference condition (neutral vs. incongruent). In contrast, the analysis of the ratio scores, which take into account differences in naming speed between groups, produced an insignificant difference between groups. Of course, the selection of the appropriate dependent measure hinges very much on one's theory, and often, this has not been made explicit enough to support the particular measure selected.

A subsequent study examined this issue in a different way. Buchanan et al. (1994) first regressed the incongruent scores on the neutral scores in the normal control group and computed a regression weight. Then they applied this regression weight to the schizophrenia performance in the neutral condition to estimate patients' performance in the incongruent condition. The measure of interference was the difference between estimated and observed RTs in the incongruent condition. Given that both the estimated and observed RTs were influenced by general slowness, the significantly augmented interference effect found for the deficit schizophrenia patients was determined not to be the result of general slowing in the patients.

Liddle and Morris (1991) employed partial correlation to deal with a similar question. They found that the performance of schizophrenia patients on a card incongruent Stroop condition correlated with both psychomotor poverty and disorganization. The first correlation could be explained by general slowness and hesitation in vocal production as this correlation shrank to an insignificant level when the measure of reading color words in black was partialled out. In contrast, partialling out this same measure from the correlation between naming incongruent color names and disorganization did not change the significance of the correlation.

Summary: Statistical control for patients' slowing was executed only in a few studies, and in those studies, the augmented interference was significant only for a subgroup of patients. In addition, most studies that employed the single-trial version of the Stroop task did not report augmented RT interference for the schizophrenia patients, despite the fact that the patients were significantly slower than controls. Note that if general slowness is centrally involved in the significant effects in those studies, it should have affected the interference component and not only the facilitatory component. This means that there is no straightforward relation between general slowness and augmented interference or facilitation.

This conclusion has a general implication for the study of patient populations. In many studies, patients exhibit general slowness in their responding. Many researchers correct for this slowness by analyzing ratio scores or similar scores. Such corrections are applied under the implicit assumption that experimental effects are proportional to the general speed of responding; that is, slower responding brings about larger effects. If this is not the case (e.g., Stroop effect in schizophrenia patients), the application of such procedures could result in "overcorrection" that may either hide real effects or make the effects more difficult to detect.

NEURAL STRUCTURES

This section is not intended to be an exhaustive review of the literature pertaining to the neural structures underlying the Stroop effect. However, we think that the current discussion will benefit from such a review, as short as it might be.

Despite a long history and wide range of use, the neural mechanisms underlying performance on the Stroop task are still not completely understood (Henik & Salo, 2003; MacLeod & MacDonald, 2000). Abnormal or increased Stroop effects have been correlated with multiple structures within cortical and subcortical regions of the brain (Bench et al., 1993; MacDonald, Cohen, Stenger, & Carter, 2000; Pardo, Pardo, Janer, & Raichle, 1990; Turken & Swick, 1999). A number of neuroimaging studies with both patients and normal controls have shown the involvement of both the anterior cingulate cortex (ACC) and the frontal lobes during the execution of the Stroop task (Bench et al., 1993; Carter et al., 1998; MacDonald et al., 2000; Nordahl et al., 2001; Ruff, Woodward, Laurens, & Liddle, 2001; Yamaguchi, Toyoda, Xu, Kobayashi, & Henik, 2002). Some have suggested that successful performance on attention tasks, such as the Stroop task, require the involvement of an executive attention network, which includes the anterior cingulate, frontal lobes, and basal ganglia (Posner & Raichle, 1994). This network is involved in detecting and selecting the target stimulus while maintaining the set or instructions that distinguish between relevant and irrelevant stimuli in the given task (Carter et al., 1998; MacDonald et al., 2000).

The regions that have shown activation during the Stroop task are some of the same regions that have been noted to be abnormal in patients with schizophrenia (see Shenton, Dickey, Frumin, & McCarley, 2001, for review). Abnormal ACC activation has been reported in patients with schizophrenia both at rest and during the execution of the single-trial Stroop task (Carter et al., 1997; Nordahl et al., 2001; Yucel et al., 2002), with significant correlations emerging between incongruent error rates and ACC metabolism. Abnormal frontal activation has also been observed in schizophrenia patients both at rest (Ingvar & Franzen, 1974) and during the execution of a wide variety of tasks (Berman, Zec, & Weinberger, 1986; Hazlett et al., 2000; Rubia et al., 2001). These functional abnormalities within fronto-cingulate regions in schizophrenia patients may underlie some of the findings of abnormal Stroop performance reported in this clinical population. This rapidly growing domain of

brain imaging research on the Stroop effect will no doubt increasingly inform our interpretation of the behavioral work.

DISCUSSION

The history of studying attention in schizophrenia patients with the Stroop test spans a period of almost 50 years. The first study using the card version in schizophrenia patients was published in 1960, and the first single-trial study appeared in 1969. The longevity of this task as a measure of attentional function in schizophrenia patients lies in the reliability of the task in measuring response conflict. Although results from both normal controls and psychiatric patients can vary according to the version employed, as well as methodological issues within each version, the basic Stroop interference effect is a robust phenomena observed in almost all individuals. The motivating factor in reviewing the Stroop studies conducted with schizophrenia patients was to determine what insights, if any, this attentional test has revealed about attentional function in patients with schizophrenia and what insights about cognitive function in general can be gained from these studies.

The results reviewed can be summarized as follows: (a) Schizophrenia patients exhibit enlarged interference with the card version of the Stroop task; (b) schizophrenia patients exhibit augmented facilitation with the single-trial version of the Stroop task; (c) differences in psychiatric symptomatology may contribute to the differences in the schizophrenia Stroop findings; (d) extended time between trials enhances interference effects in schizophrenia patients; (e) medication does not modulate Stroop interference; and (f) imaging studies point to a network of neural structures within the anterior attentional network that is likely to be dysfunctional in patients with schizophrenia.

This pattern of findings suggests that when distracting information is presented in isolation (i.e., one trial at a time), schizophrenia patients actually have adequate attentional resources to avoid being excessively influenced by the distracting information. This would explain the finding of normal RT interference when the single-trial version of the task is used compared to the card version. In contrast, when multiple attentional demands appear, as in the card version, attentional processes in schizophrenia patients are strained, leading to increased interference effects. In addition, when the schizophrenia patients are required to maintain attention over extended intertrial intervals, deficits in attentional performance increase.

These findings are consistent with deficits displayed on other tasks, such as the Continuous Performance Test of Attention (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) and working memory tasks (Goldman-Rakic, 1994), and thus, the findings are not unique to the Stroop task itself. It appears that when the context of the task is weakened, as can happen with long intertrial intervals, schizophrenia patients display a pattern of increased errors and increased reaction times on incongruent trials. Thus, attentional deficits in schizophrenia patients, as revealed by the different forms of the Stroop task, result from a combination of factors such as (a) task complexity, (b) the ability to use context, (c) the ability to efficiently allocate a finite pool of attentional resources, (d) the ability to maintain task set, and (e) the interaction between these factors and Stroop inhibition itself. Sustainment of task set may be one of the key factors in the Stroop task and has been at the core of major theoretical accounts, such as that of Cohen, Dunbar, and McClelland (1990) in which attentional task weights are crucial in explaining interference and facilitation.

Numerous studies have raised concerns over the interpretation of the results from the traditional card version of the Stroop test (Baxter & Liddle, 1998; Boucart et al., 1999; Chen et al., 2001; Salo et al., 2001). All of these studies suggest that factors extraneous to the individual Stroop stimulus itself may be contributing to the increased interference observed in the schizophrenia patients when the classical card version is employed. Failure to perform well on the traditional version of the Stroop test is likely to be more related to the ability to focus spatial attention rather than the ability to inhibit the irrelevant word dimension in the Stroop stimulus itself. Such a conclusion is supported by this review. It appears that the ability to avoid being distracted by immediate distracting information, when it is presented in isolation as in the single-trial Stroop task, is intact. Future studies using Stroop stimuli in schizophrenia patients will benefit from careful attention to methodology to better understand which attentional abilities are intact and which are compromised in patients with schizophrenia. This careful characterization of cognitive function in schizophrenia patients will yield important information applicable to neuropsychiatry and cognitive science in general.

Although the primary goal of this review was to synthesize the Stroop findings from the schizophrenia literature, this review also has wide-ranging implications for the interpretation of the Stroop effect in general. An analysis of the schizophrenia Stroop findings suggests that the facilitatory and interference components of the Stroop effect involve dissociable mechanisms that are modulated by different factors, including medication

and temporal parameters associated with task administration. In an earlier section, we suggested that the duration of the intertrial interval might introduce additional aspects of selective attention that can modulate the Stroop effect. It is quite possible that although these factors may have only minor effects in healthy subjects, they might have much larger effects in clinical populations. The insights gleaned from this review have revealed a great deal about attentional function in patients with schizophrenia as well as generating additional questions related to the cognitive research on the Stroop effect. It is the complexity and richness of the Stroop task itself that has supported its survival as a tool of cognitive assessment for more than 6 decades. The continued use of this tool in schizophrenia patients will serve to expand our knowledge of cognitive function in this prevalent psychiatric disorder.

NOTES

1. When Salo, Henik, Nordahl, and Robertson (2002b) manipulated response stimulus intervals (RSI) between blocks, the response times (RTs) to the incongruent trials increased by approximately 50% at the long RSI in the schizophrenia patients, although this increase did not reach statistical significance.

2. Mirsky et al. (1984) studied the Genain quadruplets, all of whom were monozygous women who suffered from schizophrenia. This was a follow-up study of these four patients who had been studied in the past. There was no control group, and no statistical tests were presented.

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