Journal of Experimental Psychology:
Human Perception and Performance
1984, Vol. 10, No. 5, 622-639

A Horse Race of a Different Color: Stroop Interference Patterns With Transformed Words

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Four experiments investigated Stroop interference using geometrically transformed words. Over experiments, reading was made increasingly difficult by manipulating orientation uncertainty and the number of noncolor words. As a consequence, time to read color words aloud increased dramatically. Yet, even when reading a color word was considerably slower than naming the color of ink in which the word was printed, Stroop interference persisted virtually unaltered. This result is incompatible with the simple *horse race* model widely used to explain color-word interference. When reading became extremely slow, a reversed Stroop effect—interference in reading the word due to an incongruent ink color—appeared for one transformation together with the standard Stroop interference. Whether or not the concept of automaticity is invoked, relative speed of processing the word versus the color does not provide an adequate overall explanation of the Stroop phenomenon.

Stroop color-word interference is one of the most reliable and compelling phenomena to have been discovered in experimental psychology. Almost every student taking an introductory psychology course has grimaced while trying to say "blue," not "red," in response to the word RED written in blue ink. But this phenomenon is more than just an attention-attracting demonstration. The task of naming the color of the ink in which a color word is presented provides a rich testing ground for theories of cognitive processes. Thus, the Stroop procedure has been used to test theories of semantic memory (Klein, 1964; Warren, 1972), of bilingual memory organization (Magiste, 1984; Preston & Lambert, 1969), of reading (Martin, 1978), of attention (Neill, 1978), and of automaticity (Kahneman & Chajczyk, 1983), to single out only a few. Yet the main theoretical question continues to be the source of Stroop interference itself—what underlies this powerful and deceptively simple phenomenon?

In the original version of the task (Stroop, 1935), two types of stimuli were used. The first set consisted of incongruent stimuli (e.g., RED in blue ink). The second set, a control set, consisted either of color patches, in the ink-naming condition, or color words printed in black ink, in the word-reading condition. When the task was to name the ink color of incongruent stimuli, there was an increase in ink naming time relative to that for control stimuli. This difference typically is referred to as the Stroop effect. On the other hand, when the task was to read the word, incongruency of the ink color with the word had little effect on word reading time. Put another way, no *reversed Stroop effect* was obtained. The asymmetry of interference in the ink naming and word-reading tasks is the basic datum to be explained.

Relative Speed Explanations for the Stroop Effect: The Horse Race Model

Stroop (1935) and most subsequent researchers (cf. Dyer, 1973) have explained the fact that interference occurs only when the task is ink naming as a direct outcome of

A preliminary version of this work was presented at the annual meeting of the Psychonomic Society in San Diego, November 1983.

This research was supported by Grants A7459 and E6532 from the National Sciences and Engineering Research Council Canada to the second author.

We wish to thank Paul Kolers for his encouragement and advice at the beginning of this project, and our reviewers, particularly James H. Neely, for their insightful comments.

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word reading being faster than color naming. Since Cattell's (1886) pioneering work, the processing time advantage for reading words versus naming objects or colors has been replicated often (e.g., Fraisse, 1969). This advantage for reading words has given rise to the *relative speed hypothesis* of interference. Basically, if the wrong dimension of a stimulus is processed prior to the right dimension (where right and wrong are defined by task demands), interference will result.

The most frequently cited version of the relative speed hypothesis is that of Posner (1978, p. 92): "the direction of interference depends upon the time relations involved. Words are read faster than colors can be named; thus a color-naming response receives stronger interference from the word than the reverse." Morton and Chambers (1973, p. 396) expressed this same view: "Our position is that, in a task which involves the naming of one value of a stimulus, the presence of another stimulus value in a different attribute will interfere in proportion to the relative speeds of naming the attributes." In like manner, Palef and Olson (1975, p. 201) argue that "whether one obtains verbal interference effects on non-verbal decisions, as in the classical Stroop test, or non-verbal interference effects on verbal decisions depends on the relative speeds with which the two forms of information are processed." Dyer (1973), Palef (1978), Logan and Zbrodoff (1979), and Smith and Magee (1980) each adopt a similar stance in the context of a variety of quite different experimental settings. The simplicity of the relative speed hypothesis is certainly appealing, and a fair amount of evidence appears to be consistent with it.

A popular metaphor in the Stroop literature derives from the relative speed hypothesis. This is the *horse race* model of interference. Morton and Chambers (1973) characterize the Stroop effect as a race between two responses, one of which (the word) is processed faster than the other (the ink color). This preserves the relative speed idea. In the case of RED printed in blue ink, *red* arrives at the output buffer before *blue* does, even when the required response is *blue.* Although processed in parallel up to the output buffer, the buffer is single channel, and the two responses must compete for entry. Consequently, the Stroop effect is localized in the response output phase. As Morton and Chambers (1973, pp. 396–397) conclude, "The simplest hypothesis, consistent with all the evidence, is that the interference occurs after naming." The extra time taken to respond when the two dimensions are incongruent is attributed to "overcoming" the incorrect response. In the horse race metaphor, the wrong horse wins the race.

Accounts similar to that of Morton and Chambers have been offered by Klein (1964), Dyer (1973), Warren (1972), and Palef and Olson (1975). Other researchers, most notably Posner and Snyder (1975), have added the extra assumption that word reading is faster than color naming because reading is an *automatic* process. Automatic processes are regarded as being very fast and involuntary, without attentional demand (Posner, 1978; Shiffrin & Schneider, 1977). According to this view, the subject automatically reads the word, even when the instructions are to ignore the word and focus only on the ink color. Automatic word reading is faster than nonautomatic ink naming; the consequence is Stroop interference. The automaticity account has much the same underlying structure as does the response competition explanation offered by Morton and Chambers (1973). Again, interference is localized late in the response phase: "The usual Stroop effect arises because of response competition between vocal responses to the printed word and the ink color . . . color naming and reading go on in parallel and without interference until close to the output" (Posner, 1978, pp. 91–92). This automaticity explanation for the Stroop effect is thus a variant of the relative speed hypothesis.

Varieties of Horse Race Models: Two Different Tracks

Two main classes of horse race models have been proposed—the simple stage models we have just been describing and the more complex interactive models. The first class contains the simple horse race models, such as those of Stroop (1935), Klein (1964), Morton and Chambers (1973), Palef and Olson (1975), and Posner and Snyder (1975). These models maintain (a) that processing of the ink color and the word occurs in parallel up to the response buffer, (b) that the word is processed faster than the ink color, and (c) that interference occurs in the buffer when the incorrect word-based response has to be overcome. The major virtue of these simple horse race models is their ease of testability. They permit localization of interference in a fairly direct fashion, usually at a late stage of processing (e.g., Morton & Chambers, 1973; Posner, 1978).

The second category of models places the interference at a late stage in processing as well, although generally prior to response output. This sort of explanation is characterized by the *cascade* model of McClelland (1979), wherein a host of potential responses receive activation beginning at the onset of a stimulus, with the range of possible correct responses narrowing as processing progresses until a single candidate is selected as the response. Proctor (1978), Regan (1978), and Seymour (1977) have explained their data in this way. Formal accounts of interference effects have been proposed by Schweickert (1983) and by Eriksen and Schultz (1979). The major difficulty with such explanations is deriving testable predictions from them.

In these models, there is what Eriksen and Schultz describe as a *continuous flow* of information. In the Stroop task, operations on the word and the ink are seen as going on in parallel, each feeding forward partial results in a priming type of situation (e.g., Regan, 1978), but with the set of primed responses becoming ever more restricted as processing continues. For stimuli with more than one dimension, as on incongruent trials, priming may accrue to responses along dimensions other than the target dimension. Depending on the level of this nontarget response activation, there can be inhibition of the target response (e.g., Neill, 1978). Thus, the source of Stroop interference is priming of the wrong response. Although the effect appears near the response phase of processing, the conception of interference offered by these more complex models is quite different from that provided by the simple stage models of interference.

Predictions From a Simple Horse Race Model

Three major predictions emerge from the simple horse race, or relative speed of processing model. Two relate to the standard Stroop situation where easily read color words are printed in readily identified ink colors, while the third relates to instances where the normal speed relationship between word and ink is altered in some way. The first is that the presence of a conflicting color word should interfere with the naming of the ink color in which the word is printed. This, of course, is the normal Stroop effect, which has been confirmed widely (see, for example, the reviews by Jensen & Rohwer, 1966; Dyer, 1973). The second prediction is just as direct—the presence of a competing ink color should not affect the processing of a color word; that is, ordinarily there should be no reversed Stroop effect. Although considerably fewer studies exist here, the evidence again seems consistent with the prediction. The third prediction is potentially more revealing: It should be possible to reverse this standard asymmetrical pattern by speeding up the identification of the ink color or, as is more often attempted, by slowing down the reading of the word. What is the evidence in support of the third prediction?

The first test of this prediction was carried out by Stroop (1935) in one of the lesser known experiments in his famous article. He gave subjects extensive practice in naming ink colors, reasoning that this would reduce their ink naming times and possibly reverse the normal pattern, which he attributed to faster reading of words. He did indeed find a reduction in ink naming times, and the ink colors interfered with word reading, but the effect was very fleeting, lasting only for a single test. Unfortunately, he did not examine the pattern in ink naming after training to ascertain whether interference had disappeared there (or at least been reduced), as would be predicted. Nevertheless, his basic result does seem consistent with the third prediction.

Surprisingly, little subsequent attention was devoted to reversing the Stroop effect. When finally this prediction was tested again, it was in the context of slowing down word reading rather than speeding up color naming. The rationale was as follows. If word reading is slowed to the point where color naming is actually faster on average, then processing the ink color should interfere with reading the word. Furthermore, standard Stroop interference should diminish correspondingly, ultimately vanishing as word reading times all become slower than ink naming times. As the relationship between the two response-time distributions changes, so must the pattern of interference.

Gumenik and Glass (1970) slowed down word reading by covering the word with a mask, and reported that an incongruent ink color did interfere with word reading. They also claimed that normal Stroop interference decreased when the words were masked, both results consistent with the horse race account. However, Dyer and Severance (1972) were concerned that this result might be artifactual because Gumenik and Glass had their subjects practice color naming just before the word reading. Furthermore, Dyer and Severance argued, Gumenik and Glass had omitted an essential control group—a neutral word reading condition. In a replication designed to rectify these problems, Dyer and Severance failed to observe a significant reversed Stroop effect even in the first session, although Dyer (1973) later argued as if the effect had been significant.

Several other studies have sought to demonstrate reversed Stroop interference, but generally in tasks somewhat more removed from the standard procedure than were the studies just described. Uleman and Reeves (1971) reported a reversed Stroop effect when subjects scanned a list of words in incongruent ink colors for a particular color word. However, as Dyer (1973) has noted, their neutral word stimuli may have been more legible than their incongruent stimuli, making their reversed Stroop effect artifactual (but see Dalrymple-Alford & Azkoul, 1972). Martin (1981) obtained a reversed Stroop effect when she had subjects sort Stroop stimuli into separate piles for each color word. She was also able to increase the magnitude of the reversed Stroop effect by having the subjects carry out a standard Stroop task before doing the word-sorting task. Even with this manipulation, however, the reversed Stroop effect was quite small. Still, it is the existence of the effect, not its size, that is predicted by the simple horse race account.

The study that tackles the reversal in interference pattern most directly is that of Palef and Olson (1975). Using the words *above* and *below* and varying their position on the screen, they studied time to identify the word or its position. When spatial information was processed faster, it interfered with judgments about the word, but the word did not interfere with judgments about the position. When word meaning was processed faster, this pattern was reversed. Although not perfectly analogous to the Stroop task, this is precisely the pattern expected by the relative speed account. Initially, then, the prediction that a reversed pattern of interference should be possible seems to be upheld.

Yet these findings have been called into question in a recent study by M. Glaser and W. Glaser (1982). They tested the speed of processing hypothesis directly by presenting the word prior to the ink or the ink prior to the word, varying the stimulus onset asynchrony. When the word preceded the ink, they replicated Dyer's (1971) finding of decreased interference with an increased amount of time between the word and the ink. But when the ink was presented before the word, there was no hint of interference even with an onset asynchrony of 400 ms. As all horse race models would expect a reversed Stroop effect to appear with such a large stimulus onset asynchrony, this finding of no interference was extremely surprising.[1] It is noteworthy that W. Glaser and Düngelhoff (1984) have replicated these findings in the context of the picture-word interference task as well.

For such a clear prediction from such a simple model, it is surprising that the reversed Stroop effect has been so difficult to demonstrate. If it is only the relative speeds of processing the ink color and the word that determine the interference, it ought to be a straightforward matter to overturn the usual pattern. Yet the reversed Stroop effect remains a very unstable phenomenon. Only Martin's effect was obtained using a fairly standard version of the Stroop task, and the most direct tests to date—those by Glaser and Glaser (1982) and by Glaser and Düngelhoff (1984)—failed to uncover any reversed Stroop

[1] In a later experiment, when there were relatively few congruent trials, ink color did interfere with word reading. In this case, the subjects were using the ink color to predict the word that was about to appear, thereby altering the usual Stroop situation. Quite possibly, different processes were involved, as Glaser and Glaser (1982) suggested.

interference at all with ink pre-exposures of 400 ms. With the simple horse race model and these previous results in mind, we turn now to our own experiments.

Rationale for the Present Experiments

Our basic hypothesis was that it should be possible to test the simple horse race account of the Stroop phenomenon by presenting the color words in unusual orientations, such as upside down or backwards.[2] We will refer to these stimuli as *transformed* words. Kolers (1976) and Navon (1978) have found that subjects must engage in considerable extra processing to read transformed words, as evidenced by longer reading times for transformed words than for normal words. Navon (1978) and Masson and Sala (1978) have found that reading transformed text is influenced by subjects' strategies. Thus, according to a strong automaticity theory (cf. Kahneman & Chajczyk, 1983), transformed word reading is a nonautomatic or controlled task. The attention that the subject allocates to the task should affect how the transformed word is processed.

Now consider the predictions about patterns of interference that can be derived from a relative speed of processing account, beginning with the naming of ink colors in the standard Stroop situation. If the Stroop effect stems from a race between the word and the ink color, interference should be sharply reduced or even eliminated when the color words are presented in an unusual orientation. Because this manipulation will make word reading extremely slow, the word will reach the response buffer after the name of the ink color, and little or no interference should occur in naming the ink.

The second prediction concerns the time to read the transformed words in a conflict situation. A simple horse race model predicts that the ink color should interfere with word reading when word reading is slower than ink naming. In such a model, which does not identify either ink naming or word reading as automatic, it is the relative speeds of processing the color and the word that count. Thus, the horse race model predicts a reversed Stroop effect here; this was one of the two primary motivations that led us to undertake this research.

Originally, we had a second motivation. We had hoped to explore the development of the normal Stroop effect in this series of experiments using transformed words. When subjects are exposed to transformed stimuli for the first time, we expected that there would be no Stroop interference but that, with extended practice in reading transformed words, the Stroop effect would appear. This follows from a simple horse race model. Our aim was to track the time course of this development. Schiller (1966) has shown that when young subjects practice reading, reading becomes a faster process than ink naming. This is accompanied by the emergence of the Stroop effect. Lund's (1927) results with adults show a similar pattern. We anticipated a similar result for transformed word reading. Our only precedent was an experiment by Liu (1973), who found a reduction in interference during ink naming for words in an upside-down orientation. However, Liu did not examine the effects of transformation on word reading when ink colors conflicted.

Two types of transformed words were used in our experiments. The two particular transformations that we selected were backwards stimuli such as *der,* and stimuli that were both upside down and backwards, such as *ɹəp*. These two orientations were selected on the basis of the number of transformations that are made to a normal word to derive a transformed word. Backwards words undergo one transformation, reversal of the order of the letters. Upside-down-and-backwards words undergo two transformations, reversal of letter order and inversion.

Navon (1978) found that subjects respond to upside-down-and-backwards words slower than to backwards words. Thus, to begin this line of research, we used both types of transformations in Experiment 1. We predicted that there should be less Stroop interference for upside-down-and-backwards words than for backwards words because two transformations should make reading more difficult than one transformation. This should also be

[2] In a way, our logic for transforming the words is similar to that of Glaser and Glaser (1982) for varying the stimulus onset asynchrony, although our procedure has the advantage of retaining integrated stimuli (i.e., the word and the ink color always are presented together in our experiments).

evident in the word reading times. Following the same logic, there should be a greater reversed Stroop effect for upside-down-and-backwards words than for backwards words. We included a condition with Stroop stimuli in a normal orientation as a standard against which the interference obtained with the transformed stimuli could be assessed.

Experiment 1

To begin, a very simple experiment was constructed. Using just five ink colors and their corresponding words, we planned to examine interference patterns for transformed words and to compare these to the patterns obtained with words in their normal orientation. Additionally, we included a manipulation of orientation difficulty. In one part of the experiment, we used a single transformation, with words typed backwards. In the other part of the experiment, there were two transformations, with the words typed backwards *and* upside down. It seemed plausible, given the simple horse race model, that orientation difficulty would influence interference patterns. In particular, the model predicts that the more difficult it becomes to read the transformed words, the more likely it is that standard Stroop interference should diminish and reversed Stroop interference should begin to emerge.

Method

Subjects. Thirty-two students from introductory psychology courses at the Scarborough campus of the University of Toronto volunteered to participate. Sixteen were assigned to each of the orientation subexperiments.

Materials. The stimuli were typed onto sheets of paper in black ink in a Courier typeface. These sheets were then photographed on high-contrast black-and-white 35-mm film. The negatives, white characters on a black background, were covered with colored film to produce color words in each of the five ink colors. The stimuli were then mounted in 35-mm slide frames. The resulting stimulus set was made up of the words RED, BLUE, GREEN, YELLOW, and ORANGE, and their respective ink colors. In the ink-naming condition, the control stimulus was XXXX in each of the five ink colors; in the word-reading condition, the control stimuli were the five color words in white ink.

Instrumentation. The stimuli were presented using a random-access slide projector (Kodak Ektagraphic 960). Stimuli were projected on a screen 1 m away from the subject and subtended a visual angle from 3.5° to 7°. Onset of a stimulus started a Lafayette timer (Model 54035); the subject's spoken response into a microphone tripped a voicekey that stopped the timer. Responses were manually recorded.

Design. The experiment was split into two parts. Experiment 1A used normal words and words in a backwards orientation. Experiment 1B used normal words and words in an upside-down-and-backwards orientation. Otherwise, the two subexperiments were the same in all respects. The design of each of the experiments was a 2 × 2 × 3 repeated measures factorial, representing two orientations (normal or transformed), two tasks (name ink or read word), and three degrees of congruency (congruent, incongruent, and control).

Procedure. On the ink-naming trials, subjects were instructed to say the color of the ink, ignoring the word. On the word-reading trials, subjects were instructed to read the word aloud and to ignore the ink color in which the word was typed. Each trial began with the experimenter giving a warning signal, the word NEXT. One second later, the stimulus appeared, staying on the screen for 2 s. Presentation of a slide activated a timer that stopped with the subject's spoken response. Subjects were instructed to be as accurate as they possibly could and were informed by the experimenter of any mistakes they made.

Subjects were given five practice trials at the beginning of each block of 60 trials and a 2-min break between blocks. Each block of trials consisted of 20 congruent, 20 incongruent, and 20 control trials, randomly intermingled. There were four different blocks of trials: transformed ink naming, transformed word reading, normal ink naming, and normal word reading. The two blocks of transformed stimuli always preceded the two blocks of normal stimuli. Within each orientation, the order of ink-naming and word-reading blocks was counterbalanced across subjects.[3]

Results[4]

The mean reaction times for correct responses in Experiments 1A and 1B are shown in Figures 1 and 2, respectively. Each data point is based on approximately 320 correct-response observations. Errors in all conditions other than incongruent ink naming were less than 2%. Errors in the incongruent ink-naming conditions for the three orientations were approximately 3%.

Separate analyses of variance were performed on the ink naming and word reading reaction times for both Experiments 1A and 1B. On the whole, these confirmed the pat-

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[3] Originally, the order of performing word-reading and ink-naming blocks was expected to affect performance. In particular, it seemed reasonable to expect that having to read transformed words prior to naming their ink colors might enhance Stroop interference relative to the order where ink naming preceded word reading. As it happens, order of blocks had no effect in any of the experiments, and will not be mentioned further.

[4] The alpha level for statistical decisions in all of the experiments was set at .05, although most results were significant at the .001 level.

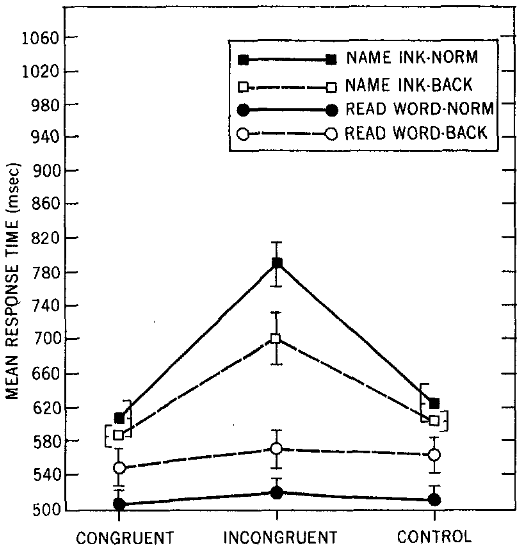

Figure 1. Experiment 1A: Mean correct response times for naming inks and reading words, presented separately for normal (NORM) and backwards (BACK) words. (The three congruency conditions are congruent, incongruent, and control. Standard error brackets are displayed for each condition. Because they are plotted on the same scale, this and all subsequent figures can be overlaid.)

terns of results evident in Figures 1 and 2. The 2 × 3 analyses involved the factors of orientation and congruency. Thus, we will describe four analyses—ink naming and word reading for each experiment.

First consider ink naming in Experiment 1A. There was a significant effect of orientation, $F(1, 15) = 7.60$, $MS_e = 5{,}361$, indicating slower ink naming of normal words than of backwards words. Congruency also had a significant effect, $F(2, 30) = 122.58$, $MS_e = 1{,}800$, with incongruent stimuli slower than congruent or control stimuli. The significant interaction, $F(2, 30) = 11.07$, $MS_e = 1{,}177$, reveals that there was greater interference due to normal words than due to backwards words for ink naming. Pairwise comparisons of the means using Tukey's HSD (honestly significant difference), procedure were conducted. They revealed that incongruent stimuli were significantly slower than congruent and control stimuli for both orientations. Furthermore, although the control and congruent conditions were equal for both orientations, the incongruent conditions differed. Put simply, words in both orientations produced interference in ink naming, but there was more interference for normal words.

Now consider word reading times. Again, both main effects were significant. The significant effect of orientation, $F(1, 15) = 41.43$, $MS_e = 1{,}345$, shows that backwards words took longer to read than did normal words. Although not readily apparent in Figure 1, there was also a significant effect of congruency on word reading, $F(2, 30) = 23.40$, $MS_e = 150$. Tukey HSD tests revealed that there was a significant facilitation for both orientations, with the congruent condition being faster than the incongruent and control conditions in both cases. The marginally significant interaction, $F(2, 30) = 2.76$, $MS_e = 162$, $p = .08$, suggests that the degree of facilitation is greater for backwards words than for normal words.

The findings for Experiment 1B, using upside-down-and-backwards stimuli, were very similar to those for Experiment 1A, using backwards stimuli. The analysis of variance for ink naming times revealed a significant main effect of congruency, $F(2, 30) = 172.39$, $MS_e = 2{,}163$, indicating that reaction times for the incongruent condition were slower than those for the congruent and control conditions. Orientation did not affect response latency significantly, $F(1, 15) = 1.63$, $MS_e = 2{,}789$. However, there was a significant inter-

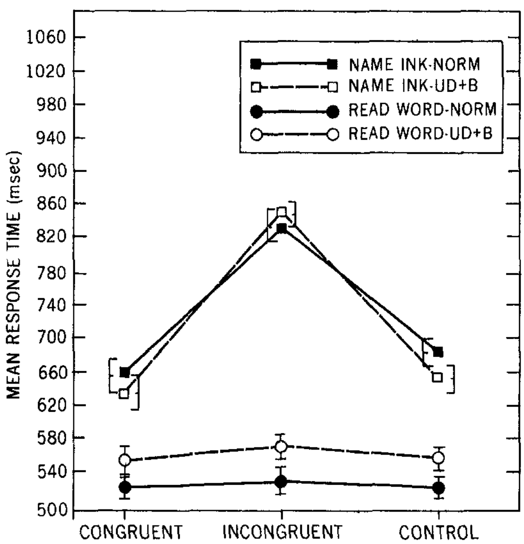

Figure 2. Experiment 1B: Mean correct response times for naming inks and reading words, presented separately for normal (NORM) and upside-down-and-backwards (UD + B) words. (The three congruency conditions are congruent, incongruent, and control. Standard error brackets are displayed for each condition.)

action of orientation with congruency, $F(2, 30) = 4.05$, $MS_e = 1{,}095$. Pairwise comparisons of means using the HSD procedure showed that incongruent stimuli were responded to slower than were congruent or control stimuli for both orientations. Ink naming patterns were identical for both orientations in Experiment 1B.

In the word-reading data, only the effect of orientation was significant, $F(1, 15) = 11.82$, $MS_e = 2{,}550$. Upside-down-and-backwards words were read more slowly than were normal words. Neither the main effect of congruency, $F(2, 30) = 1.30$, $MS_e = 720$, nor the interaction ($F < 1$) was significant, implying that both interference and facilitation were absent for word reading.

Discussion

The main finding of Experiments 1A and 1B was that subjects experienced interference in naming ink color for the transformed words as well as for the normal words. Both backwards and upside-down-and-backwards words increased reading times relative to normal words. However, backwards words produced less interference than did normal words in ink naming (Experiment 1A), whereas upside-down-and-backwards words did not (Experiment 1B). Perhaps the somewhat larger effect of the backwards transformation on word reading in Experiment 1A is responsible for the difference between the interference patterns in the two experiments.

These results must be viewed in light of our failure to slow down the process of reading words very dramatically. Most of the predictions set out at the beginning do not apply if transformed word reading is not made slower than normal word reading. In retrospect, it is apparent why the orientation manipulation did not work. With so few words—only the five color words—there was little uncertainty about which word was being displayed. Even by inspecting a single letter (cf. Regan, 1978), subjects could tell readily which color word was being displayed, thereby providing the condition necessary for interference to develop. At this point, then, the results are completely in accord with a simple horse race account.

It is somewhat more difficult to align the results with a simple automaticity account. Because the subjects had no previous training in reading transformed words, it would be hard to describe their word reading as automatic. Thus, it does not follow from a simple automaticity account that interference should be observed in ink naming for the transformed words. Of course, it would be possible to salvage this view by assuming that the limited stimulus set somehow allowed word processing to run off virtually automatically. Given the small size of the stimulus set and the fact that the subjects are searching for color-relevant information, they need little information to process the words. Yet subjects showed interference even on the first appearance of a transformed incongruent color word in the practice trials. One way of testing this explanation in terms of small set size is to increase set size by adding noncolor words. This should make reading the words still more difficult. Subjects would be forced to engage in much more extended processing to determine whether the word is a color word and, if so, which particular color word it is. This was the goal of Experiment 2.

Experiment 2

Our initial attempt to slow down word reading by transforming the words failed largely because of the small set of words used. Subjects could identify the five color words readily because they were the only words in the experiment. To prevent this ready identification, we embedded the color words in a larger set of noncolor words similar in many surface respects to the color words. This manipulation should reduce ease of identification and slow reading time for the transformed words but not for the normal words. The change in reading speed should have corresponding effects on interference patterns according to the simple horse race explanation, as predicted for Experiment 1. Furthermore, because color words will appear rarely in such a design, subjects cannot readily determine whether the word is a color word. Therefore, there should be a reduction in interference in this experiment. Because particular orientation was not an important issue in this experiment, only one transformation—upside-down-and-backwards—was used.

Method

Subjects. Forty students from introductory psychology at the Scarborough campus of the University of Toronto participated in the experiment. None of them had participated in the previous experiment.

Materials. The same color-word stimuli that were used in Experiment 1 were used in Experiment 2. A further set of stimuli was taken from the Battig and Montague (1969) category norms. Nine categories were selected on the basis of finding one 3-letter, one 4-letter, one 5-letter and two 6-letter words to correspond to the lengths of the five color words. All words were selected from ranks 5 to 20 of each category. Of the 120 stimuli prepared, 30 were color words and 90 were noncolor words. Each of the 45 noncolor words was presented twice in the ink-naming condition and twice in the word-reading condition. These noncolor words appeared once in one ink color, and once in another ink color. Each ink color was presented an equal number of times over trials. Turning now to the Stroop stimuli, each color word appeared four times in the ink-naming condition, twice as a congruent item and twice as an incongruent item. Each color word appeared six times in the word-reading condition, twice congruent, twice incongruent, and twice as a control (word in white ink).

Instrumentation. Stimuli were presented using a random-access slide projector (Kodak Ektagraphic 960). Stimulus presentation was controlled using an Apple II+ computer, which randomized slide orders, closed the projector shutter, and recorded reaction times from the voicekey apparatus.

Design. The design of the experiment was a 2 × 2 × 3 mixed design, with a between-subjects factor of orientation (normal and upside-down-and-backwards) and within-subjects factors of task (name the ink or read the word), and congruency (congruent, incongruent, and control). There were 20 subjects in each orientation condition. Orientation was a between-subjects factor because the addition of noncolor words necessitated too many trials for a subject to complete without fatigue in a single session.

Procedure. Subjects were tested individually. In the color-naming condition, the subjects were told that they would see a word and that they were to say the color of the ink that the word was printed in. They were told to ignore the words. In the word-reading condition, they were told to say the word aloud, ignoring the color of ink in which it was printed. Subjects in the upside-down-and-backwards word-reading condition were informed of the nature of the transformation as an aid to their reading.

The subjects were given 10 practice trials at the beginning of each block of trials. The experiment consisted of one block of word-reading trials and one block of ink-naming trials with the order of blocks counterbalanced across subjects. Each block consisted of 120 randomly ordered trials of a particular task. Of these trials, 90 were noncolor words and 30 were the critical color words. For the critical trials, there were 10 congruent, 10 incongruent, and 10 control trials in each block. Each trial began with the experimenter's saying NEXT. One second later, the slide appeared and stayed on until the subject responded or until 2 s had elapsed. Subjects had a two-min break between the two blocks of 120 trials.

Results

The addition of noncolor words to the stimulus set had the desired effect of slowing down the time to read the transformed stimuli. Average time to read the noncolor words was 602 ms (SE = 18.43) when in the normal orientation and 1,787 ms (SE = 102.30) when transformed. Ink-naming times for the noncolor words were 678 ms (SE = 17.31) when in the normal orientation and 669 ms (SE = 21.62) when transformed.

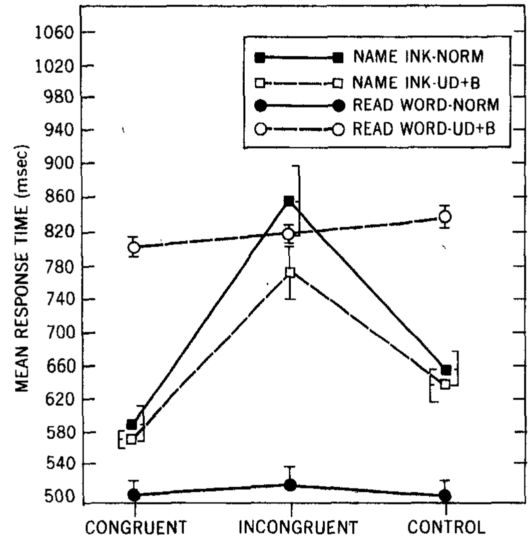

Figure 3. Experiment 2: Mean correct response times for naming inks and reading words, presented separately for normal (NORM) and upside-down-and-backwards (UD + B) words. (Color words were mixed with noncolor words, but the two orientations occurred in separate blocks. The three congruency conditions are congruent, incongruent, and control. Standard error brackets are displayed for each conditon.)

The mean reaction times for correct responses to the color stimuli are shown in Figure 3. Responses to the noncolor stimuli were excluded from the analysis, their purpose being simply to make identification of the color words more difficult. Each data point is based on approximately 200 correct-response observations. Seven reaction times longer than 3 s were eliminated. Errors accounted for less than 2% of the data in all conditions except incongruent ink naming. For this condition, errors were 11% for normal words, and 14% for upside-down-and-backwards words.

Two analyses were conducted on the mean correct reaction times for each subject, one for ink naming and one for word reading. These analyses were 2 × 3 mixed analyses of variance, with orientation as the between-subjects factor and congruency as the within-subjects factor. Both confirm the pattern of results evident in Figure 3. For the ink-naming data, the only significant effect was that of congruency, $F(2, 76) = 107.35$, $MS_e = 5{,}790$. Tukey HSD tests demonstrated that there was reliable interference and reliable facilitation in ink naming from both normal words and upside-down-and-backwards words. Although there was not a significant effect of orientation, $F(1, 38) = 1.67$, $MS_e = 26{,}145$, the interaction of congruency with orientation was marginally significant, $F(2, 76) = 2.69$, $MS_e = 5{,}790$, $p = .07$. This reflects the reduced interference in the upside-down-and-backwards condition relative to the normal condition.

The other 2 × 3 analysis was conducted on the word reading data. The only significant effect here was orientation, $F(1, 38) = 144.27$, $MS_e = 20{,}852$, capturing the huge difference in reading times for normal and transformed words. Neither the main effect of congruency ($F < 1$) nor the interaction, $F(2, 76) = 1.41$, $MS_e = 3{,}671$, was significant. Thus, there is no evidence of either interference or facilitation in the word-reading data of Experiment 2.

Discussion

The addition of noncolor words to the stimulus set had the desired effect of slowing down the time to read the upside-down-and-backwards words. The time to read a transformed word increased by over 300 ms from Experiment 1. As in Experiment 1, however, there was still a large amount of interference with ink-color naming in the upside-down-and-backwards condition. Furthermore, the interference with ink naming was identical for normal and for transformed words, despite the large difference in the word-reading condition. Finally, there was no evidence of a reversed Stroop effect in the word-reading data for the transformed words.

Even though upside-down-and-backwards word reading is 300 ms slower than normal word reading and 100 ms slower than ink naming, there is no change in the pattern of interference relative to normal words. The presence of the word still interferes with naming the ink, whereas the presence of the ink color does not interfere with reading the word. A simple horse race explanation for the Stroop effect must predict at least some change in the interference pattern under these circumstances, given the shift in the distributions of response times. Interference with ink naming should have been reduced and a corresponding reversed Stroop effect should have emerged for the transformed words.

Given the fact that previous researchers have found some evidence of a reversed Stroop effect, it could be argued that word reading has not been slowed down enough even in this experiment and that for this reason interference with word reading did not occur. Although this argument seems to rely on some rather peculiar assumptions about the distributions of response times across conditions, it remains a possibility. We designed Experiment 3 to test this hypothesis by making the word-reading task even harder.

Experiment 3

Ambler and Proctor (1976) compared mixed and blocked presentations of stimuli in two orientations in a letter-matching task. They found that subjects used a different strategy in the mixed condition than in the blocked conditions. A subject's processing of normal letters was the same regardless of whether orientation was blocked or mixed. Mixing orientations had a detrimental effect on upside-down letter matching, however. With this in mind, we mixed upside-down-and-backwards stimuli with normal stimuli in the same block in Experiment 3, expecting that upside-down-and-backwards word-reading times should become even longer than in Experiment 2. Moreover, any tendency to read the transformed words in the ink-naming block should be reduced by this manipulation.

Experiment 3 tests the hypothesis that when word reading is made more difficult, the deleterious effects of the incongruent word on ink naming should decrease. Half of the words are in a normal orientation and half are in an upside-down-and-backwards orientation. When the order of presentation of stimuli in the two orientations is random, the subject should find word reading a harder task than in the previous experiment. If the simple horse race model is correct, the slower word-reading latencies should produce a decrease in interference for ink naming of transformed stimuli. In addition, there should be a reversed Stroop effect; processing the ink color should begin to interfere with reading upside-down-and-backwards words.

Method

Subjects. Twenty University of Toronto students were paid $4.00 each to participate in a 45-min session. None of the subjects had participated in either of the previous two experiments.

Materials. The same slides were used as in Experiment 2. Of the 120 stimuli, 60 words were in an upside-down-and-backwards orientation and 60 words were in a normal orientation. Of the 60 stimuli in a particular orientation, 45 were noncolor words and 15 were color words, a 3:1 ratio as in Experiment 2. Each of the five color words appeared once as a congruent, once as an incongruent, and once as a control stimulus.

Instrumentation. The apparatus was the same as in the previous experiment.

Design. The design of the experiment was a 2 × 2 × 3 repeated-measures factorial, representing two orientations (upside-down-and-backwards and normal), two tasks (name the ink and read the word), and three levels of congruency (congruent, incongruent, and control).

Procedure. Each subject received 10 practice trials at the beginning of each block of trials. There were two blocks. Subjects were told that the stimuli would consist of words in two orientations and that the stimuli would appear in a random order. They also were told that the transformation of the word was upside-down-and-backwards. The order of ink-naming and word-reading blocks was counterbalanced across subjects, and block order did not influence performance.

Results

Mixing the orientations produced a large increase in the time to read words in the transformed orientation, whether noncolor or color words. The mean time to read a noncolor word was 692 ms (SE = 25.25) in the normal orientation and 1,914 ms (SE = 238.00) when transformed. Mean color-naming time for the noncolor words was 707 ms (SE = 16.85) in the normal orientation and 675 ms (SE = 13.85) when transformed. Reaction times for these noncolor stimuli were not included in any subsequent analyses.

The mean reaction times for the correct responses to the Stroop stimuli are shown in Figure 4. Each data point is based on approximately 100 observations. All reaction times above 3 s were eliminated from the analysis. Errors in all conditions, except the incongruent ink-naming trials, accounted for no more than 3% of the data. Errors for the incongruent ink-naming trials were 18% for normal stimuli, 12% for upside-down-and-backwards stimuli.

A 2 × 3 repeated measures analysis of variance on the ink-naming data revealed a significant main effect of congruency, $F(2, 38) = 72.85$, $MS_e = 7{,}690$. Tukey HSD tests confirmed that incongruent stimuli were responded to slower than congruent or control stimuli, but that the latter two conditions were equal. There was significant interference, but no facilitation. Neither the main effect of orientation ($F < 1$) nor the interaction of orientation with Congruency, $F(2, 38) = 1.06$, $MS_e = 5{,}015$, approached significance, demonstrating that the pattern of means was identical in ink naming for words in both orientations.

Turning to the word-reading data, the new pattern evident in Figure 4 was confirmed by the analysis of variance. There was a significant effect of orientation, $F(1, 19) = 30.98$, $MS_e = 87{,}516$, with transformed words taking considerably longer to read than normal words. Although the main effect of congruency did not reach conventional levels of significance, $F(2, 38) = 2.39$, $MS_e = 8{,}073$, $p = .10$, there was a significant Orientation ×

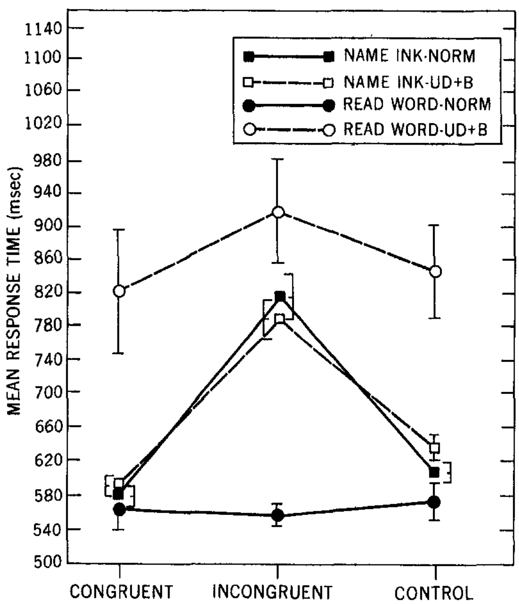

Figure 4. Experiment 3: Mean correct response times for naming inks and reading words, presented separately for normal (NORM) and upside-down-and-backwards (UD + B) words. (Color words were mixed with noncolor words, and the two orientations were mixed together in the same block. The three congruency conditions are congruent, incongruent, and control. Standard error brackets are displayed for each condition).

Congruency interaction, $F(2, 38) = 3.44$, $MS_e = 9{,}447$. An HSD analysis demonstrated that the incongruent condition times for reading transformed words were longer than the congruent and control condition times. For the first time, there is evidence of a reversed Stroop pattern in the word-reading data for the transformed words. That is, incongruent transformed stimuli seem to be at a disadvantage now even when the task is to read the words, not to name the inks.

Discussion

The results of Experiment 3 replicate and extend those of Experiment 2. Upside-down-and-backwards word-reading latencies were made extremely slow, nearly 300 ms longer than normal word reading and nearly 200 ms longer than ink naming. Thus, mixing the two orientations had the desired effect of making word reading more difficult. However, as in Experiment 2, there was no decrease in interference for ink naming, even though the difficulty of word reading had increased. In fact, the ink-naming times for the two orientations are identical in all three conditions. Ink naming has not even changed overall in response to slower word reading, as comparison of these results with those of Experiment 2 shows. These results make it ever more difficult to continue adherence to the simple horse race model. Stroop interference should diminish or disappear as word reading becomes progressively slower; instead, interference remains virtually identical for normal and transformed words.

The intriguing new result in Experiment 3 is that processing the color of the ink appears to be interfering with reading the word. Surprisingly, though, the reversed Stroop effect and the normal Stroop effect exist concurrently. According to a simple horse race type of analysis (cf. Dyer, 1973; Morton & Chambers, 1973), there should be a decrease in the amount of interference in ink naming when word reading is made so difficult that a reversed Stroop effect occurs. Contrary to this prediction, there was not a decrease in the amount of interference with ink naming to parallel the rise in interference with word reading. In fact, the amount of interference with ink naming obtained in all three experiments has remained relatively impervious to experimental manipulation. This suggests the provocative possibility that the amount of interference obtained in the Stroop task for ink naming and for word reading are independent of each other. In Experiment 4, we planned to pursue this reversed Stroop effect. By now, our strategy should be quite predictable—we tried to make word reading even more difficult.

Experiment 4

In Experiment 4, the word-reading task was made even more difficult by presenting half of the words in an upside-down-and-backwards orientation and the other half of the words in a backwards orientation. These were presented in mixed blocks, and there were no words in the normal orientation. In this case, words in the two orientations are read in different directions—the backwards words are read from right to left and the upside-down-and-backwards words are read from left to right. Thus, the subject's reading task is made even more difficult. Based on the simple horse race model and following from the results of the previous experiments, we expected that there should be a reversed Stroop effect for both the backwards and upside-down-and-backwards words. But the simple horse race model makes this prediction only in exchange for the reduction or elimination of regular Stroop interference. Would this elusive trade-off finally appear?

Method

Subjects. Twenty University of Toronto undergraduate students were paid $4.00 each to participate in a 45-min session. None of the subjects had participated in the previous experiments.

Materials and procedure. The materials and the procedure were the same as in Experiment 3, with the exception that the two orientations used were both transformed words, upside-down-and-backwards and backwards.

Design. The design of the experiment was a $2 \times 2 \times 3$ repeated-measures factorial, representing two orientations (upside-down-and-backwards and backwards), two tasks (name the ink and read the word), and three levels of congruency (congruent, incongruent, and control).

Results

As predicted, mixing words in the two unusual orientations slowed down reading times considerably. Mean time to read noncolor words was 2,250 ms (SE = 200.00) for upside-down-and-backwards words and 2,348 ms (SE = 206.00) for backwards words. Mean color-naming times for the two types of transformed stimuli were 726 ms (SE = 22.83) for the upside-down-and-backwards words and 751 ms (SE = 28.36) for the backwards words. Reaction times for these non-Stroop stimuli were not included in subsequent analyses, and all reaction times greater than 3 s also were eliminated.

Figure 5 displays correct-response data in the form of mean reaction times for each condition. Each point represents approximately 100 observations. Errors accounted for less than 2% of the data in all conditions except incongruent ink naming, where they accounted for 7% of the data for both orientations. There was also a 6% error rate in the incongruent and control backwards word-reading conditions.

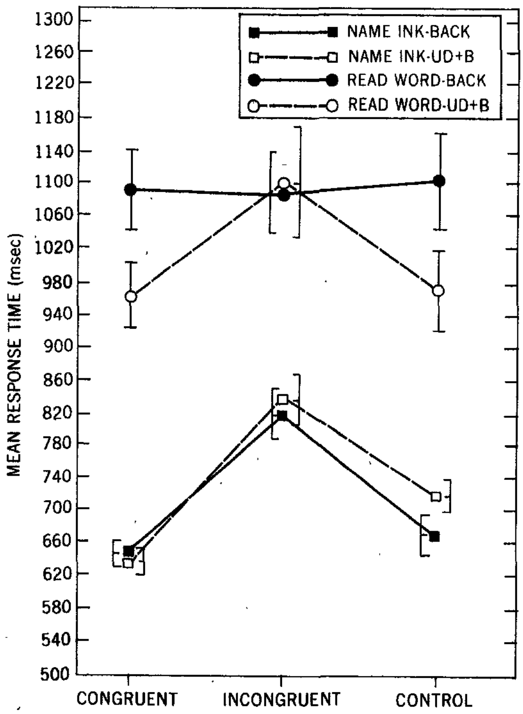

Figure 5. Experiment 4: Mean correct response times for naming inks and reading words, presented separately for backwards (BACK) and upside-down-and-backwards (UD + B) words. (Color words were mixed with noncolor words, and the two orientations were mixed together in the same block. The three congruency conditions are congruent, incongruent, and control. Standard error brackets are displayed for each condition.)

Analysis of variance confirmed the pattern of results evident in Figure 5. Looking first at ink-naming times, there was a significant main effect of congruency, $F(2, 38) = 32.14$, $MS_e = 9{,}747$, but neither the main effect of orientation, $F(1, 19) = 1.67$, $MS_e = 5{,}295$, nor the interaction of orientation with congruency ($F < 1$) was significant. As in Experiment 3, an HSD analysis revealed that both transformations showed reliable (and virtually identical) Stroop interference, but no reliable facilitation.

Turning to word reading, there was a significant effect of orientation, $F(1, 19) = 6.30$, $MS_e = 40{,}860$, with the backwards words taking longer to read overall than the upside-down-and-backwards words. Although the congruency effect was only marginally significant, $F(2, 38) = 2.77$, $MS_e = 21{,}914$, $p = .07$, the Orientation × Congruency interaction was significant, $F(2, 38) = 4.89$, $MS_e = 17{,}210$. Strangely, Tukey HSD tests revealed that there was significant reversed Stroop interference only for the upside-down-and-backwards stimuli. There were no differences in reaction time among the three levels of congruency for the backwards words but, for the upside-down-and-backwards words, there was a significant difference between the incongruent words and the congruent and control words. The pattern observed for the upside-down-and-backwards words here replicates the reversed Stroop effect obtained in Experiment 3. What is surprising is that it occurred for only one of the two types of transformed words and that it occurred in the presence of identical Stroop interference patterns for the two transformations.

Discussion

The results of Experiment 4 generally replicate those of Experiment 3. Reading of upside-down-and-backwards words and of backwards words has been slowed down to a full second, yet there has been almost no change in the amount of interference obtained for ink-color naming across experiments. There was, however, a significant reversed Stroop effect for upside-down-and-backwards words but not for backwards words. None of the existing accounts can explain this outcome, especially given the asymmetry of the reversed Stroop effect. What we have thus far is a highly consistent, if puzzling, pattern of results, including one of the few demonstrations of a reversed Stroop effect—indeed, a robust reversed Stroop effect—to be reported using the color-word task. With or without the automaticity assumption, the simple horse race model cannot accommodate our results. Apparently, interference in the Stroop task is considerably more complicated than such models would lead us to believe.

General Discussion

The four experiments reported here addressed two predictions derived from the simple horse race model of the Stroop effect. The first prediction was that when word reading is slowed down, there should be a reduction in the amount of interference obtained in the ink-naming task. The second prediction was that when word reading is slower than ink naming, the ink color should interfere with word reading—a reversed Stroop effect should appear. To test these predictions, transformed word reading was made progressively slower over the four experiments. The results of these experiments will be discussed initially in terms of simple horse race models. Then the implications for interactive models of the Stroop effect will be considered.

Arguments Against Simple Horse Race Models

The first prediction from the simple horse race model proposed by Dyer (1973), Klein (1964), Morton and Chambers (1973), and most recently, by Posner (1978) is that slowing down word reading should reduce the amount of interference in the Stroop task. On the basis of this, our initial hypothesis was that transforming the words should slow down word reading, resulting in less interference in the ink-naming task. Experiments 1A and 2 showed a nonsignificant trend in favor of this hypothesis. Transforming the words did slow down reading, and there was some reduction in the amount of interference for transformed stimuli. However, in Experiments 3 and 4, where word reading was made even slower, there was no decrease in interference at all. Even though transformed word reading was 300 ms slower than normal word reading in Experiment 3, there was a virtually identical pattern of interference for normal and transformed stimuli in the ink-naming task. In Experiment 4, when transformed word reading was 500 ms slower than normal word reading had been in the previous experiments, there was still no reduction in the amount of interference in the ink-naming task. These results disconfirm the first prediction derived from the simple horse race model. Stroop interference is not reduced when word reading is slowed, even when the slowing is quite dramatic.

One possible way of accounting for the ink-naming data is to assume that the time taken to read a transformed word in the word-reading task is not a valid indicator of how long it takes to identify the word in the ink-naming task. It may take less time for a transformed color word to activate a potential response in the ink-naming task than it does to read that word aloud in the word-reading task. This type of explanation necessitates new stages or mechanisms not contained in the simple horse race model being considered. Such additional mechanisms are, however, consistent with the interactive models to be discussed later.

The second prediction derived from the simple horse race model was that an incongruent ink color should interfere with word reading when word reading is slower than ink naming. Although transformed word reading was slower than normal word reading in Experiment 1, there was no reversed Stroop effect. This result is consistent with the simple horse race model because transformed word reading was still faster than ink naming. However, when we consider the results of the other experiments, we again encounter data that are difficult for the simple horse race model to explain. First, although there was no difference in word-reading times for congruent and control words across Experiments 2 and 3, there was a reversed Stroop effect for transformed words in Experiment 3, but not in Experiment 2. A simple horse race model would predict, incorrectly, that if there is no change in the time it takes to read words for congruent and control stimuli, there should be no change in the amount of interference obtained for incongruent stimuli. Clearly this did not happen between Experiments 2 and 3. Second, in Experiment 4, a reversed Stroop effect occurred for words in an upside-down-and-backwards orientation, but not for words in a backwards orientation. This happened even though backwards word reading was *slower* than upside-down-and-backwards word reading. Again, this result disconfirms any theory that maintains that the relative speeds of processing the word and ink are solely responsible for the production of interference.

A third prediction can be derived from the simple horse race model by combining the first prediction of reduced interference and the second prediction of a reversed Stroop effect. Taken together, these lead to the prediction that there should be a trade-off between the amount of interference obtained in the ink-naming and the word-reading tasks. Both Dyer (1973) and Gumenik and Glass (1970) have made such claims. As word reading is made progressively slower, the amount of interference in the ink-naming task should decrease. As Morton and Chambers (1973, p. 396) state, "The amount of interference is a monotonic function of the ease of recognition of the words." This should also produce a reversed Stroop effect to the extent that the standard Stroop effect is reduced. In Experiments 3 and 4, a reversed Stroop effect did appear, yet there was no reduction in the amount of interference in the ink-naming task. Thus, a third prediction of the simple horse race model is refuted.

An additional assumption incorporated into some versions of the simple horse race model is that word reading is automatic (e.g., Posner, 1978). The claim is made that reading the words is obligatory and, hence, that words are read faster than ink colors can be named. This type of explanation would predict that if word reading is made nonautomatic (or voluntary), Stroop interference should not occur. Most of the work on reading transformed text (e.g., Kolers, 1976; Masson & Sala, 1978; Navon, 1978) suggests that the transformations employed here should prevent automatic processing of the words. Yet, in all four experiments, the transformed words interfered with ink naming.

If the criteria for automaticity that have been proposed by Posner and Snyder (1975) or by Shiffrin and Schneider (1977) are accepted, then it must be concluded that transformed word reading is not an automatic process; rather, this task requires considerable attentional involvement. Normal word reading times were not lengthened by the addition of noncolor words to the stimulus set, but transformed word reading times were considerably lengthened. Furthermore, normal word reading was not affected by changing the number of orientations in a single block of trials from one to two (as in Experiment 3), yet transformed word reading was slowed down markedly. In the face of these data, addition of the automaticity assumption cannot salvage the simple horse race model.

An alternative explanation for the presence of interference when word reading is not automatic is to assume that the presence of congruent items in the stimulus set encouraged subjects to attend to the words, and it is this that caused the interference (cf. Logan & Zbrodoff, 1979). However, the presence of congruent trials is not critical to the observation of Stroop interference ordinarily. Both Lowe and Mitterer (1982) and Kahneman and Chajczyk (1983) obtained a large Stroop effect even when no congruent items were included. In fact, the interference was only slightly less than when congruent stimuli were present. Furthermore, if subjects were attending to the words because of the presence of congruent items, a large facilitation effect for the congruent items would be expected to occur because the word should activate the same response as the ink. However, only a minimal facilitation effect occurred in two of the five experiments (Experiments 1A and 2). Consequently, it is unlikely that the presence of congruent stimuli can account for the interference obtained in these experiments, particularly when one considers that the words are in an unusual orientation and are difficult to read.

In summary, only one of the predictions derived from the simple horse race model—the reversed Stroop effect—has been confirmed by the present series of experiments. The failure to eliminate normal Stroop interference by making word reading slower than ink naming, the occurrence of the Stroop and reversed Stroop effects at the same time, and a reversed Stroop effect occurring for one transformed orientation but not for the other, are all inconsistent with the simple horse race model. These results lead us to reject any explanation of the Stroop effect that is based *solely* on the relative speed of processing of the ink and the word. Our findings, coupled with those of Glaser and Glaser (1982) and Kahneman and Chajczyk (1983), suggest that simple horse race models are not an adequate explanation for the Stroop effect.

Interactive Models—A Horse Race of a Different Color

An alternative to the rejected simple horse race models is the interactive sort of model of processing proposed by Eriksen and Schultz (1979), McClelland (1979), Flowers and Wilcox (1982) and Taylor (1977). The models proposed by Eriksen and Schultz (1979) and Taylor (1977) are particularly relevant to the present series of experiments because the flanker task that they used is similar to the Stroop task in many respects. We will describe the basic features of these models first and then discuss their application to the present findings.

One of the fundamental features of interactive models in general can be seen in Eriksen and Schultz's version. Here, evidence is built up in favor of a potential response throughout stimulus processing, rather than just when a particular response is selected at the response output stage. Interference is not due to a limited capacity response buffer being filled, but to the amount of *priming* each potential response receives. Correct responses are inhibited to the extent that other potential responses are activated, thereby accounting for the standard Stroop effect. A further assumption in Taylor's model is that the processing of one stimulus is affected by the ongoing processing of the other stimulus. There is considerable opportunity for interactive processing to influence the time it takes to read a word or to name the ink of a compound stimulus.

How would such a model explain why words interfered with ink naming in our experiments, even though word reading was slower than ink naming? As suggested earlier, this could be because the time to read a word in the word-reading task is not a true indication of how long it takes to identify the word in the ink-naming task. In the word-reading task, there is a large response set and the subject must respond to color and noncolor words alike. In the ink-naming task, on the other hand, there are only five potential responses regardless of the number of possible stimulus words. When there is a small response set, as in the ink-naming task, the threshold of activation for a particular response may be lowered, resulting in faster recognition of the transformed color words. This would explain why one-letter color "words" also produce interference (Regan, 1978).

Eriksen and Schultz (1979), Neill (1978), and Regan (1978) all have argued that the response set primes certain responses more than other responses. Thus, the threshold for activation of primed responses should be less than that for unprimed responses. Even in an unusual orientation, then, a color word can still activate a potential response when that response already is primed by the task of ink naming. This would also explain why the noncolor words produced hardly any interference: They were not potential responses. The interactive model thus provides an explanation for the continued existence of the normal Stroop effect in the four experiments, despite the fact that word reading is slower than ink naming.

Interactive models also take into account the time relations involved in the processing of the relevant and irrelevant aspects of the stimulus. The models proposed by Eriksen and Schultz (1979), Taylor (1977), and Flowers and Wilcox (1982) all predict that if the processing of the irrelevant aspect of the stimulus is faster than that of the relevant aspects of the stimulus, interference should occur. Therefore these models predict that a reversed Stroop effect should occur when word reading is slower than ink naming, as happened in Experiments 3 and 4. However, these models have difficulty explaining why a reversed Stroop effect occurred for the upside-down-and-backwards words but not for the backwards words, given that reading times for the backwards words were slower overall. Current formulations of these models provide no mechanism(s) to account for this finding.

Interactive models explain the basic Stroop effect by specifying that the interference occurs while the subject is attempting to build up evidence in favor of one response relative to other responses. The presence of the reversed Stroop and standard Stroop effects at the same time may be explained in terms of differences in the size of the response sets in the ink naming and word reading tasks. Potential color responses are primed in the ink-naming task, but not in the word-reading task, where the set of responses is much larger.

The major advantage of these interactive models is that they specify the temporal relationships that must exist between the stimuli for interference to occur. In this way, they preserve the best feature of the simple horse race models. In addition, they provide the flexibility to accommodate the complexities already observed in the Stroop task and in other interference situations. These interactive accounts have the potential to provide an overarching explanation of interference in processing, but there are many hurdles yet to be cleared. We have identified one such hurdle—the fact that reversed Stroop interference occurs only in some experimental situations. We must be able to predict those situations. As any experienced race fan knows, handicapping a horse race is never an easy matter. Apparently, this one is no exception.

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Received December 1, 1983
Revision received April 19, 1984 ■

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