

The reverse Stroop effect

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In classic Stroop interference, manual or oral identification of sensory colors presented as incongruent color words is delayed relative to simple color naming. In the experiment reported here, this effect was shown to all but disappear when the response was simply to point to a matching patch of color. Conversely, strong reverse Stroop interference occurred with the pointing task. That is, when the sensory color of a color word was incongruent with that word, responses to color words were delayed by an average of 69 msec relative to a word presented in gray. Thus, incongruently colored words interfere strongly with pointing to a color patch named by the words, but little interference from incongruent color words is found when the goal is to match the color of the word. These results suggest that Stroop effects arise from response compatibility of irrelevant information rather than automatic processing or habit strength.

The Stroop effect is one of the easiest and most powerful effects to demonstrate in a classroom, but not the easiest to explain. Nearly every introductory psychology book provides a demonstration of the phenomenon: that it is difficult to name the ink color in which different color words are printed. But what is the proper explanation? Perhaps the weakest hypothesis concerning Stroop interference is that "words are processed faster than are colors." It is true that reading words is faster than naming colors, but this seems to be a matter of response compatibility, rather than perceptual speed. After all, the words require no translation (Virzi & Egeth, 1985). In trying to emphasize that the interference effect depends on greater response compatibility between printed and spoken words, however, one risks suggesting the automaticity account (see Besner, Stolz, & Boutilier, 1997, for a recent critique), which suggests that color words interfere with color naming because they are automatically processed.

The present experiment was designed to put both the speed theory and the automaticity theory to rest, if only for a little while, by using the simple nonverbal response of pointing to the appropriate color in a visual array. This will be shown to completely reverse the direction of interference, and thus to produce a reverse Stroop effect in which sensory colors interfere with identifying color words. No one thinks pointing to colors is automatic, although, like naming, pointing can be construed as a simple deictic act (literally, indexical). Nonetheless, the perceptual grouping of matched colors in an array (target and

response) seems so likely to be a sufficient guide for pointing (just as the printed word maps easily to the internal array of possible verbal responses) that the symmetry of this task with the traditional task seems quite good. Here, it can be argued, the response is suited to the sensory information, rather than to the verbal.

In the traditional Stroop effect (Stroop, 1935; see MacLeod, 1991, for a review), naming the print color of a word is delayed if the word itself is a color word that names a different color (e.g., responding "red" to the word "blue" displayed in red letters is slower than responding "red" to a red patch of color). Conversely, very little reverse Stroop interference is found for reading a color word printed in a conflicting color (i.e., responding "blue" in the above example). One promising account of Stroop interference supposes that it is due to response competition, which, when the response is verbal, gives verbal inputs a privileged position (e.g., Fitts & Posner, 1967; MacLeod, 1991; Treisman & Fearnley, 1969). Although it is well established that Stroop interference is still obtained (though reduced) when manual, keypress responses are given (e.g., Keele, 1972; Pritchatt, 1968), these kinds of tasks may involve implicit verbal coding at the response-selection stage. That is, subjects may think of their right index finger as touching the "blue" key, and mediate their responses on the basis of these verbal labels.

At least two prior experiments have attempted to eliminate Stroop interference by the use of color matching. Pritchatt (1968) showed a reduction in interference by a kind of matching task using color markers over the buttons, but little reversal. McClain (1983) reported elimination of Stroop interference using colored buttons, but did not investigate reverse Stroop interference. In both cases, colored patches were placed on or near buttons that were to be used as responses. Conversely, Besner et al. (e.g., 1997) have routinely studied normal Stroop interference using color-marked buttons and have had no trouble obtaining the standard Stroop effect.

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Treisman and Fearnley (1969) showed that making same/different judgments about pairs of Stroop-like stimuli showed interference only when the comparison was between different modes (verbal and visual) rather than within the same mode (but, cf. Morton & Chambers, 1973). They did not demonstrate a response type for which visual information had a positive advantage, however. Indeed, Egeth, Blecker, and Kamlet (1969) showed that such same/different comparisons were disrupted when the verbal information embedded in the stimuli (namely "DIFF" or "SAME") conflicted with the response itself. These kinds of findings have been used by some to support a "translational" account of Stroop interference (Virzi & Egeth, 1985). In a translational account, the argument is made that the target information must be translated into the appropriate classification modality (e.g., verbal in the standard Stroop task), whereas the distracting information is already presented in that form. If two items share a modality (i.e., are both words, or are both sensory colors), no translation between modalities is required to match them in a same/different task. Similarly, if a verbal response is required to a sensory target with a verbal foil (e.g., the word "red" printed in blue), then verbal information ("red") will be "pretranslated" and have an advantage over the sensory (blue) information, thus competing with the target response, "blue."

Flowers (1975) demonstrated a strong reverse Stroop effect in a left-right two-alternative sequential word-to-color matching task. A word ("red" or "green") was presented on a colored background (the distracting information), and then, after a blank delay, one side of the screen would turn green, the other red. The subjects had to indicate which side matched the word (and ignore the colored background). Here, again, although only two responses were possible, the response locations varied from trial to trial so that immediate perceptual information always formed the basis for response (in conjunction with verbal information presented moments before). Flowers demonstrated that this effect was clearly modulated by sensory similarity of interfering background colors to the target colors. He did not investigate the influence of this paradigm on normal Stroop interference, however, and his task differs from traditional tasks in having a delayed, binary response.

Flowers, Warner, and Polansky (1979), however, did perform a direct test of response compatibility with a numerosity analogue of the Stroop task and found reversal of the direction of interference when the response was to tap out the number of items rather than to respond verbally. Specifically, if a subject were responding to a visually presented collection of three twos, the four pertinent conditions of the experiment were to (1) respond verbally to the collection ("three"), (2) respond verbally to the digits themselves ("two"), (3) respond manually to the collection by tapping three times ("tap-tap-tap"), or (4) respond manually to the digits ("tap-tap"). Crucially, there was an interaction between focus of response and response type, such that it was easier to respond verbally to

the digits ("two") than to the numerosity of the collection, but it was easier to tap thrice than twice in this example.

The present paper reports a new kind of manual task that almost completely eliminates traditional Stroop interference and produces strong color-based interference when the task is to identify the words (reverse Stroop). The task is to point to a color by moving a mouse cursor to a patch of color corresponding to the desired response. This task is formally similar to a manual keypress inasmuch as pointing acts like naming. But pointing does so by referring to a perceptual entity (the color patch) rather than a mental category (via a categorical response).

The principal findings of the present experiment are that Stroop interference in responding to the sensory color of a conflicting color word can be eliminated and that reverse Stroop interference (interference with responding to the color named by the word) can be demonstrated with a pointing procedure in which the responses are color patches. In the Stroop (color) condition of this experiment, subjects were required to respond to the color that the target word was printed in, ignoring the word itself (which named a different color). In the reverse Stroop (word) condition, subjects were to respond to the color named by the word, ignoring its incongruent physical color. In both cases the response was to move a mouse cursor to a patch of color on the computer screen. Neutral (no-conflict) versions of each condition were also performed. Insofar as the demands of the pointing task lend themselves to the direct use of color rather than verbal information, response-competition theory predicts a strong reverse Stroop effect when subjects are required to respond to the verbal information and to disregard the perceptually salient color match. Simply put, pointing to a matching color can be accomplished without ever internally labeling the color. Pointing to a named color, on the other hand, would seem to require either categorical identification of the surrounding color patches or translation of the word into a visual code. If distracting information represents a possible response, response competition may ensue when the distractor-based response would be in conflict with the correct response.

As a further consideration, the locations of the response colors were randomly altered from trial to trial for half of the subjects to ensure dependence on visual guidance rather than on memory. In terms of information acquisition, fixed-target locations ought logically to be faster, but if memory for fixed locations tends to foster a counterproductive dependence on response categorization (e.g., as may occur with manual keypresses), the opposite result could hold for the color condition of the present task.

METHOD

Subjects

Forty Swarthmore undergraduate students participated in exchange for payment or partial fulfillment of a course requirement. Ten were assigned to each of four experimental conditions. Two additional students were excluded because of failure to follow instructions.

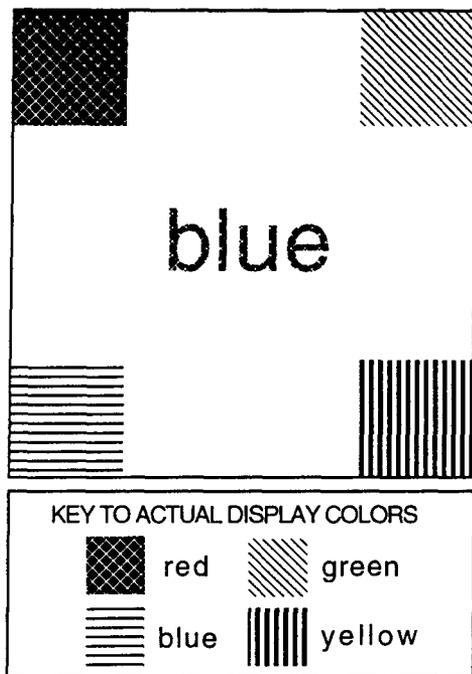


Figure 1. Display configuration to scale with a key showing display colors. Target word was presented in gray (neutral condition) or in a conflicting color (incongruent condition), which was matched to one of four square patches at the corners of the display. Color locations shown are those used in the fixed-color-location conditions of the experiment. The central fixation square, which was visible only prior to the appearance of the target word, was about half the linear size of the “u” in “blue” shown here. Note that actual color patches rather than textures were used in the experiment—and no color key was necessary.

The Task

On each trial of the experiment, subjects had to move a mouse cursor to a location (Figure 1) that corresponded in color to the color of a word on the screen or to the color that the word named.

Design

There were four between-subjects conditions in a 2×2 design. Subjects were required to identify either the color of the word or the color that the word named. In addition, the response color locations either were fixed or were variable from trial to trial. Subjects were assigned at random to one of the four conditions and each received two sessions of neutral trials as well as two sessions of incongruent trials in ABBA (or BAAB) order, so that interference effects could be measured within individuals by comparing sessions. For the word tasks, the neutral stimuli were color words presented in medium gray. For the color tasks, the neutral stimuli were furniture words (“desk,” “lamp,” “table,” “chair”) presented in color. Whether the neutral or incongruent condition came first was varied systematically between subjects.

Twelve distinct incongruent target stimuli were created by the factorial combination of four color words (“red,” “yellow,” “blue,” and “green”), with each of the three colors incongruent with that word. A session consisted of 12 blocks of 12 trials each, with stimulus order randomized within each block. The first two blocks of each session were considered as warmups and were not analyzed. In the variable-color-location conditions, the locations of the four color patches were chosen pseudo-randomly on each trial by the

computer. In the fixed-color-location conditions, the color positions were consistently as shown in Figure 1. In the neutral color conditions, the furniture words replaced the color words; thus each was paired with only three of the remaining colors.

Stimuli and Responses

The words were presented in 72-point Geneva lowercase letters against a black background at the center of a high-resolution Macintosh display (28 pixels/cm) viewed, without restraint, at a distance of about 50 cm. The colors used, specified as 8-bit RGB values, were red (255,0,0), green (0,170,51), blue (68,68,255), yellow (255,255,0), and, for the neutral color, gray (170,170,170). A white square outline, 2 pixels wide, with an internal width of 400 pixels (16° of visual angle) defined the active portion of the display. The colored response patches were 100 pixels square and were placed at the inside corners of the white square, as depicted in Figure 1.

Each trial began with the square white outline around the display region and a white square fixation mark, 20 pixels across, at its center. In the fixed-color-location condition, the four response color squares were also present. The subject initiated the trial by clicking the mouse on the fixation square. This action caused the fixation square and the mouse cursor to disappear, so as not to mask the word. (The mouse cursor later reappeared as soon as the subject moved the mouse outside the region defined by the fixation square.) After a delay of 500 msec, the stimulus word appeared and remained on the screen until response. In the variable-color-location condition, the colored response patches appeared simultaneously with the word. Response latency was defined as the time at which the mouse cursor’s tip entered one of the four colored response regions. A ballistic motion that passed the cursor through the color patch was therefore sufficient. A physical movement of the mouse by about 3 cm along the table surface sufficed to reach any patch. A beep for incorrect responses provided feedback.

RESULTS

Median response latencies were computed for correct-response trials in each session for each subject. Average median response times (RTs), as well as mean error rates (number of errors per 120-trial session), are shown in Figure 2 for incongruent and neutral trials for each experimental task.

A repeated measures analysis of variance (ANOVA) was conducted on the RT data with task (word or color) and color location (fixed or random) as between-subjects variables and irrelevant dimension (neutral or incongruent) and block (first or second) as within-subjects variables. As is evident from Figure 2, overall latencies in the word task conditions (654 msec) were substantially longer than those in the color-matching conditions [526 msec; $F(1,36) = 61.1, p < .001$], consistent with the less natural mapping from words to directional selection of colored patches. Incongruent trials were also slower, overall, than neutral trials [$F(1,36) = 41.7, p < .001$]. Crucially, however, because there was an interaction between irrelevant dimension and task [$F(1,36) = 24.7, p < .001$], separate RT analyses were carried out for each task. Note that this interaction indicates greater interference for the word task than for the color task, as is evident from Figure 2.

RTs were shorter in the second block (585 msec) than in the first [597 msec; $F(1,36) = 7.5, p < .01$], and a reliable interaction of block and irrelevant dimension indi-

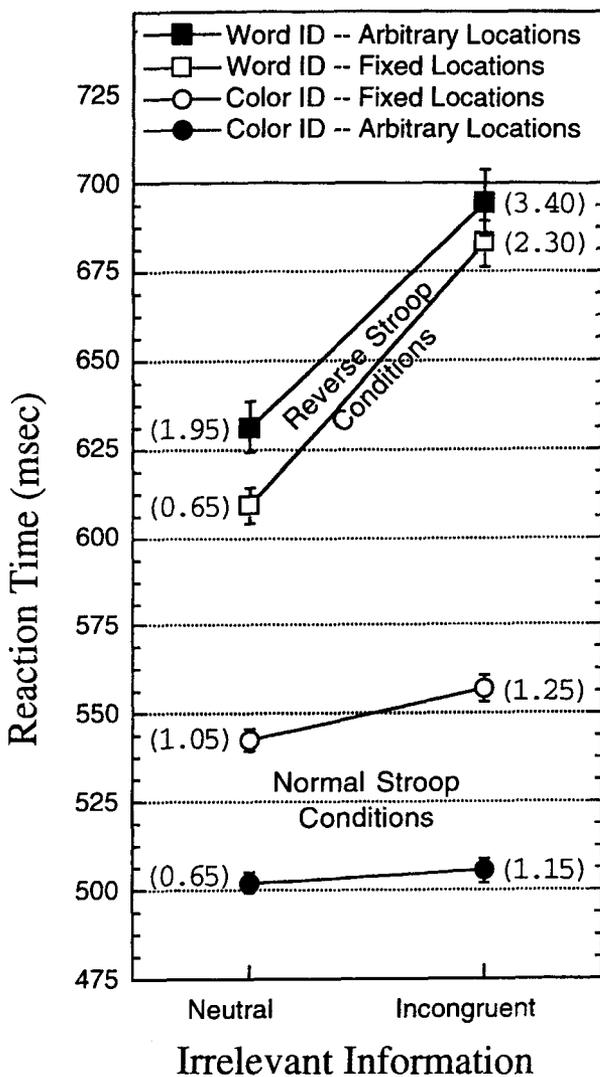


Figure 2. Averages of median reaction times as a function of task (identify word or color), color location (fixed or arbitrary), and presence of incongruent information (neutral or incongruent). Error bars represent standard errors of the mean. Lines corresponding to reverse Stroop conditions ("identify the word") and to normal Stroop conditions ("identify the color") are so labeled. Parenthetical values indicate error frequencies for the various conditions.

cated that this improvement was greater for incongruent than for neutral trials [$F(1,36) = 9.3, p < .01$]. However, these order effects, which are consistent with practice, are not relevant to our main questions and will not be considered further.

When the same ANOVA was applied to error scores, the same pattern of findings emerged: Overall errors were higher in the word condition (2.1 per session) than in the color condition [1.0; $F(1,36) = 7.5, p < .01$], and there were more errors for incongruent trials (2.0) than for neutral trials [1.1; $F(1,36) = 23.9, p < .001$]. There was also an interaction between irrelevant dimension and task

[$F(1,36) = 9.5, p < .01$], indicating greater interference effects for the word task, so error analyses were also conducted separately for each task. There was no reliable effect of block on error rates [$F(1,36) = 2.2, p > .1$].

Word-Matching Task

When the color-matching data were excluded from the analysis, the mean RT for incongruent trials (689 msec) was much longer than that for neutral trials [620 msec; $F(1,18) = 37.2, p < .0001$]. Similarly, there were more errors for incongruent trials (2.9) than for neutral trials [1.3; $F(1,18) = 24.5, p < .0001$]. There was no evidence of effects of color location in either analysis, nor did color location interact reliably with any other factors. In summary, strong reverse Stroop interference effects have been demonstrated in both RTs and error rates.

Color-Matching Task

In contrast to the results of the word task, very little Stroop interference was evident in the pointing task when the response was to the color in which the word was displayed. For the RT analysis, incongruent trials (531 msec) were, indeed, slower than congruent trials [522 msec; $F(1,18) = 4.6, p < .05$]. However, this difference (9 msec) was much smaller than that for the word task (79 msec), as was indicated by the interaction in the main analysis just reported. Moreover, the error rates for the incongruent trials did not differ reliably from those for the neutral trials for this task [$F(1,18) = 2.3, p > .10$]. Again, the interaction in the main error analysis indicates that interference was greater in the word task than in the color task. Although some Stroop interference remained, it is clear that it was inconsequential relative to the reverse Stroop effects.

Rather surprisingly, responses in the random-color-location condition (504 msec) were faster than those in the fixed-color-location condition [550 msec; $F(1,18) = 11.6, p < .01$]. It might be that fixed-response locations facilitated categorical encoding of responses as a strategy, and it might be that this was actually counterproductive in the matching task, which can be handled more rapidly by perceptual color grouping. However, in similar experiments not reported here, this particular difference has not arisen reliably (whereas the others do). Moreover, the effects of irrelevant dimension did not vary as a function of color location [$F(1,18) = 1.8, n.s.$], so I will not dwell on this further.

DISCUSSION

The results reported here indicate that using a pointing task can produce strong reverse Stroop interference while nearly eliminating traditional Stroop interference. It is worth noting that, insofar as the fixed-color-location conditions are analogous to traditional Stroop paradigms—with fixed responses for each color item—it is particularly impressive that these conditions were so effective at reversing the traditional direction of Stroop interference.

The present findings support the response-compatibility/response-competition model of Stroop interference, and are thus consistent with similar findings for numerosity (Flowers et al., 1979). They are also compatible with translational accounts (e.g., Virzi & Egeth, 1985). When responses are matched to visually guided action, visual, rather than verbal, responses are faster, and conflicting visual information is more strongly disruptive of responding to verbal information than vice versa.

Accounts of Stroop interference that depend on the purported automaticity of verbal processing of text, on the other hand, are difficult to adapt to the present results. Although a common response to a word is to read it, pointing to matching colors is not plausibly an automatic response, or even a normal response. There is nonetheless clear reverse Stroop interference in the pointing task. Insofar as the reverse Stroop parallels the traditional Stroop, the automaticity account fails for both. This is bad news for models of Stroop performance that presume a basis for the effect in automaticity or strength of association (e.g., Cohen, Dunbar, & McClelland, 1990).

Researchers using sorting-task variants of the Stroop effect, in which the stimulus itself is removed to one of several bins, have previously suggested that active manipulation reduces Stroop interference (Chmiel, 1984; Martin, 1981; Taylor & Clive, 1983; Tecce & Happ, 1964), particularly when colored labels are used for the sorting bins (Chmiel, 1984). However, reversals (i.e., strong reverse Stroop effects) may not have been as evident because sorting tasks emphasize conceptual categorization. The present task might be regarded as a single-trial-analyzable version of a sorting task, but the analogy to sorting is actually no stronger than that of naming to sorting. Moreover, the pointing task employed here may succeed because it avoids any dependence on explicit categorization. Scanning tasks (Uleman & Reeves, 1971) have shown suggestive reversal results, but these have departed substantially from any structural similarity to the traditional Stroop.

The nearest predecessor of the present effect is probably the work of Flowers (1975), discussed earlier, in which a reverse Stroop effect was demonstrated. He used keypress responses on the left or right side to a word presented on a colored background. Following the word, the two colors used, red and green were presented randomly to the left and right, and the keypress was to correspond to the side of the color that matched the word. The variable location of response locations was used to delay response by a variable interval in that experiment, but may also have served to disadvantage categorical responding in favor of visually guided action (perhaps guided by implicit apparent motion). Flowers did not investigate the traditional direction of the Stroop effect, because he did not have subjects respond to the perceived colors. Moreover, his task departs from most traditional Stroop tasks in having only a binary response set (see also Treisman & Fearnley, 1969). Apart from Flowers et al.'s (1979) investigation of response compatibility in the numerosity analogue of

Stroop interference, the present results stand as a unique demonstration of the symmetry of interference that the stimulus-matching results of Treisman and Fearnley, for example, suggested ought to be possible.

In conclusion, the data presented here show that reverse Stroop interference, the interference of colors with the response to color words, is quite strong in a color-matching pointing task for which normal Stroop interference is minimized. Unlike manual keypressing, which has traditionally failed to eliminate strong Stroop interference, pointing, even to a fixed set of locations, appears to be resistant to covert verbal labeling. These data are clearly consistent with accounts that stress the importance of response compatibility and consequent response competition in Stroop interference effects.

REFERENCES

- BESNER, D., STOLZ, J. A., & BOUTILIER, C. (1997). The Stroop effect and the myth of automaticity. *Psychonomic Bulletin & Review*, *4*, 221-225.
- CHMIEL, N. (1984). Phonological encoding for reading: The effect of concurrent articulation in a Stroop task. *British Journal of Psychology*, *75*, 213-220.
- COHEN, J. D., DUNBAR, K., & MCCLELLAND, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, *97*, 332-361.
- EGETH, H. E., BLECKER, D. L., & KAMLET, A. S. (1969). Verbal interference in a perceptual comparison task. *Perception & Psychophysics*, *6*, 355-356.
- FITTS, P. M., & POSNER, M. I. (1967). *Human performance*. Monterey, CA: Brooks-Cole.
- FLOWERS, J. H. (1975). "Sensory" interference in a word-color matching task. *Perception & Psychophysics*, *18*, 37-43.
- FLOWERS, J. H., WARNER, J. L., & POLANSKY, M. L. (1979). Response and encoding factors in "ignoring" irrelevant information. *Memory & Cognition*, *7*, 86-94.
- KEELE, S. (1972). Attention demands of memory retrieval. *Journal of Experimental Psychology*, *93*, 245-248.
- MACLEOD, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Review*, *109*, 163-203.
- MARTIN, M. (1981). Reverse Stroop effect with concurrent tasks. *Bulletin of the Psychonomic Society*, *17*, 8-9.
- MCCLELLAND, L. (1983). Effects of response type and set size on Stroop color-word performance. *Perceptual & Motor Skills*, *56*, 735-743.
- MORTON, J., & CHAMBERS, S. M. (1973). Selective attention to words and colours. *Quarterly Journal of Experimental Psychology*, *25*, 387-397.
- PRITCHATT, D. (1968). An investigation into some of the underlying associative verbal processes of the Stroop colour effect. *Quarterly Journal of Experimental Psychology*, *20*, 351-359.
- STROOP, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643-662.
- TAYLOR, A., & CLIVE, P. B. (1983). Two forms of the Stroop test. *Perceptual & Motor Skills*, *57*, 879-882.
- TECCE, J. J., & HAPP, S. J. (1964). Effects of shock-arousal on a card-sorting test of color-word interference. *Perceptual & Motor Skills*, *19*, 905-906.
- TREISMAN, A. M., & FEARNLEY, S. (1969). The Stroop test: Selective attention to colours and words. *Nature*, *222*, 437-439.
- ULEMAN, J. S., & REEVES, J. (1971). A reversal of the Stroop interference effect, through scanning. *Perception & Psychophysics*, *9*, 293-295.
- VIRZI, R. A., & EGETH, H. E. (1985). Toward a translational model of Stroop interference. *Memory & Cognition*, *13*, 304-319.