Journal of Experimental Psychology:
Human Perception and Performance
2006, Vol. 32, No. 4, 826–839

0096-1523/06/$12.00 DOI: 10.1037/0096-1523.32.4.826

Stroop Dilution Depends on the Nature of the Color Carrier but Not on Its Location

Yang Seok Cho
Korea University

Mei-Ching Lien
Oregon State University

Robert W. Proctor
Purdue University

Stroop dilution is the reduction of the Stroop effect in the presence of a neutral word. It has been attributed to competition for attention between the color word and neutral word, to competition between all stimuli in the visual field, and to perceptual interference. Five experiments tested these accounts. The critical manipulation was whether the color to be named was carried by the color word or the neutral word. Neutral words diluted the Stroop effect when they were the color carrier, but not when the color word was the color carrier. We argue that Stroop dilution is due to attentional competition between the color word and neutral word, with priority given to the color carrier.

Keywords: Stroop effect, Stroop dilution, attentional capture, attentional competition

At any given moment, many stimuli are impinging on our senses. To ensure that only the stimuli relevant to current task goals are encoded for further processing, it is necessary to impose top-down selection. Although such selection is clearly possible, it is not always complete. A classic example of incomplete top-down selection is the *Stroop effect*: A longer time is required to name an object's color when the object spells an incongruent color word (e.g., the word *green* in red ink) than when it spells a congruent color word (e.g., the word *red* in red ink) or is a neutral form (e.g., a red color bar; Stroop, 1935; see MacLeod, 1991, for a review). The Stroop effect occurs even when the color and color word are not integrated within a single stimulus. The color of a central bar is named faster when a color word located above or below the bar is congruent with the color than when it is not (e.g., Gatti & Egeth, 1978).

The Stroop effect is robust and often interpreted as indicating that a word automatically activates its name. If word recognition is fully automatic, then it should occur regardless of whether additional words are presented in other display locations. Kahneman and Chajczyk (1983), however, showed that the Stroop effect is reduced when the color word is accompanied by a neutral word, a finding they called the *Stroop dilution effect*.[1] In their Experiment 1, the Stroop effect of 121 ms obtained by presenting an irrelevant color word with a relevant color patch decreased to 65 ms when a neutral word was added to the display. This Stroop dilution effect has been replicated in several studies (e.g., Yee & Hunt, 1991). There are three accounts of the Stroop dilution effect that have been proposed: attentional capture (Kahneman & Chajczyk, 1983), visual interference (Brown, Roos-Gilbert, & Carr, 1995), and unlimited-capacity attention capture (Mitterer, La Heij, & Van der Heijden, 2003).

Kahneman and Chajczyk's Attentional Capture Account

According to Kahneman and Chajczyk (1983), word recognition requires spatial attention and is a serial process (i.e., recognition occurs for only one word at a time). When only the color word accompanies the color patch, the word will always capture attention and be recognized, thus affecting color-naming performance on all trials. When both a color word and neutral word are presented simultaneously with the color patch, only one of the words will capture attention and be recognized. The color word will impact color-naming performance on trials for which it captures attention but not on trials for which the neutral word captures attention. Assuming that the color and neutral words are equally likely to capture attention when both are present, the Stroop effect for the color-word condition should be diluted by approximately half when a neutral word is also displayed, as was the case in Kahneman and Chajczyk's Experiment 1 and in several other studies.

Consistent with the attentional capture account, Brown et al. (1995) found that, when the number of neutral words was in-

Yang Seok Cho, Department of Psychology, Korea University; Mei-Ching Lien, Department of Psychology, Oregon State University; Robert W. Proctor, Department of Psychological Sciences, Purdue University.

This research was supported in part by Army Research Office Grant W9112NF-05-1-0153. We thank anonymous reviewers for helpful comments on previous versions of the article and Motonori Yamaguchi for his assistance with data collection for Experiment 5B.

Correspondence concerning this article should be addressed to Yang Seok Cho, Department of Psychology, Korea University, Seoul, Korea 136-701. E-mail: yscho_psych@korea.ac.kr

[1] Note that reduction, and even elimination, of the Stroop effect does not necessarily imply that the meaning of the color word has not been processed (Catena, Fuentes, & Tudela, 2002; Marí-Beffa, Estévez, & Danziger, 2000).

creased up to a maximum of three, the Stroop effect decreased roughly proportionally to the ratio of color word to neutral words in the display. However, because the color patch was presented at fixation in their study, they argued that the color patch was initially attended and the color word and neutral word(s) were initially unattended. Consequently, the color word should not have been recognized, and the Stroop effect should have been negligible in all conditions. To explain the substantial Stroop effect that was actually obtained, the attentional capture account requires the additional assumption that attentional resources are drawn involuntarily to word-recognition processing.

Brown et al.'s Early Visual Interference Account

As an alternative to the attentional capture account of Stroop dilution, Brown et al. (1995) proposed an early visual interference account. This account assumes that recognition of two or more words occurs in parallel, but their combined feature representations make up complex visual patterns at an early visual processing stage. Because early visual processing of the color word is degraded when a neutral word accompanies it, recognition of the color word is impaired, resulting in a smaller Stroop effect. In Brown et al.'s words,

> multiple patterns are processed in parallel. If any are color words, Stroop effects occur but are reduced because any color word's input to lexical memory is lower in quality than if a single color word were the only pattern. Thus, lexical encoding is involuntary but can operate on several input representations in parallel, with effectiveness determined by input quality. (p. 1395)

In their Experiment 3, Brown et al. (1995) tested the effect of various types of diluting stimuli, including neutral words, pseudowords, letter strings, graphic character strings, rows of *X*s, and rows of dashes, to control the complexity of the perceptual features of the diluting stimulus. All of these stimuli produced a Stroop dilution effect, but the row of *X*s and dashes produced less dilution than the other kinds of stimuli. Brown et al. suggested that this smaller dilution effect for repetitive stimuli (the row of *X*s and the row of dashes) occurs because they are less complex than the nonrepetitive stimuli and, consequently, cause less degradation of the early visual percept of the color word.

The Stroop effect for the nonrepetitive diluting stimuli in Brown et al.'s (1995) study did not vary significantly with lexical status (word vs. nonword), suggesting that Stroop dilution is not due specifically to lexical processing. In addition, they found that the letter strings reduced the Stroop effect no more than did the other types of nonrepetitive diluters (e.g., neutral words, pseudowords), consistent with their early visual interference account. Nevertheless, Mitterer et al. (2003) found a significantly larger reduction for the letter strings than other types of nonrepetitive diluters (see also Roberts & Besner, 2005). Because complexity was approximately equal across these distractor types, Mitterer et al. argued that visual complexity cannot be the only determinant of Stroop dilution magnitude.

Mitterer et al.'s Unlimited-Capacity Attention-Capture Account

Mitterer et al. (2003) proposed an unlimited-capacity attention-capture account of Stroop dilution that also assumes that the two words, as well as the color patch, are identified in parallel. However, no perceptual interference is postulated; instead, the dilution effect is attributed to competition for attentional resources. According to Mitterer et al., the Stroop effect has two components, one automatic and the other attentional. First, because a color word activates its name automatically, selection of the correct color-naming response will be delayed when that name conflicts with the correct response for the stimulus color. Second, for those trials on which the incongruent color word captures attention, the automatic activation of the incorrect color name will be extended until attention is redirected to the color bar. This additional activation of the incorrect color name will produce continued response conflict, resulting in an additional delay in selecting the response word. The automatic component affects performance for all trials on which a color word is presented, regardless of whether it is accompanied by a neutral word, whereas the attentional component affects performance only on the subset of trials for which attention is directed to the color word. This subset will decline as more neutral words are added to the display, and hence the Stroop effect will also decline. In Mitterer et al.'s (2003) words,

> all visual transients (e.g., sudden onsets) lead to attention capture processes, and . . . multiple visual transients compete for attention capture. . . . In displays with only the color word and the color bar, only these two stimuli compete for attentional capture. If another word-like stimulus is added, three stimuli compete for attention-capture, and attention capture by the color word is less likely. (p. 32)

In other words, competition depends on the number of different stimulus objects in the display and not on where those objects are presented.

In their Experiment 2, Mitterer et al. (2003) presented a color bar and a color word, or a color bar, color word and neutral word, at locations on an imaginary circle, preceded by a cue of an outline rectangle. The cue was presented either in the center of the screen (an uninformative location cue) or surrounding the location of the upcoming target color bar (a valid location cue). To prevent eye movements, the interval between the onset of the cue and offset of the stimulus display was short (170 ms). Without a neutral word, a Stroop effect was evident (49 ms) but at smaller than typical value, and the addition of a neutral word did not reduce the size of the effect significantly (43 ms). Similar results were found regardless of the cue type. Experiment 3 used a similar method except that the location cues were not presented. It yielded a larger Stroop effect of 70 ms when there was no neutral word, with the effect diluted to 41 ms when a neutral word was present. According to Mitterer et al., the location cue prevents both the color word and neutral word from capturing attention. Because the color word does not capture attention, even when it is the only word presented, there is no attentional component contributing to the Stroop effect, which accounts for its small base value. Moreover, a neutral word cannot reduce attention to the color word since there is no attentional component to begin with, and, therefore, it does not dilute the Stroop effect. Note that Mitterer et al.'s account relies on the relatively strong assumption that words following a precue never capture attention, for which the authors provided no direct evidence.

Present Study

Of the three accounts proposed to explain the Stroop dilution effect, Mitterer et al.'s (2003) unlimited-capacity attention-capture account currently provides the best explanation. However, the evidence is far from unequivocal in this regard. The goal of the present study was to obtain additional evidence clarifying the nature of the Stroop dilution effect by directing attention initially to either the color word or the neutral word. This was accomplished by integrating the target color with the color word and presenting the neutral word in a nontarget location (Experiments 1, 2, and 5B) or vice versa (Experiments 3, 4, and 5A).

If the Stroop dilution effect is due to early visual interference or, more generally, to automatic processing, it should be evident when the color word is the carrier of the target color. However, the dilution effect should not be evident if it is due to attentional capture because attention is directed on all trials to the location of the color word. In contrast, when the neutral word is the carrier of the target color and the color word is in a nontarget location, the attentional capture account would predict a Stroop dilution effect (compared to a condition in which a color bar and color word are presented) because attention is directed initially to the neutral word.

After we had completed Experiments 1–4, a closely related study was reported by Roberts and Besner (2005). In their study, the color carrier (a color bar or a color word in some experiments and a color bar or a neutral word in the other experiments) was presented at fixation in all trials. Unlike our experiments, the responses in their study were four keypresses, made with the index and middle fingers of each hand, assigned to four colors. When a color bar was the color carrier (the standard display condition), a color word above or below the bar produced a Stroop effect of 63 ms; this effect was diluted to 24 ms when a neutral word was also present in the display. When the color word was the color carrier, the Stroop effect was larger (100 ms) and was not diluted by the presence of a neutral word. In contrast, when the neutral word was the color carrier, an additional color word produced a nonsignificant Stroop effect of only 4 ms. Risko, Stolz, and Besner (2005) obtained similar results using a visual search task. These findings, nearly complete Stroop dilution with a neutral word color carrier, are inconsistent with Mitterer et al.'s (2003) account because the meaning of the irrelevant color word should be processed automatically. This account is also inconsistent with the finding that an irrelevant neutral word produced no Stroop dilution when the color carrier was a color word, because the onset of the neutral word is a visual transient that should have drawn attention on some trials.

Whether Roberts and Besner's (2005) results generalize to vocal color-naming responses of the type used in other studies is an open question. Because keypresses have no dimensional overlap with the concept of color (Kornblum, 1992), they are less compatible than naming responses with the relevant color dimension and, even more so, with the irrelevant color word dimension (e.g., Baldo, Shimamura, & Prinzmetal, 1998). Also, although Roberts and Besner concluded that "the extent to which flanking distractors are processed depends on the nature of the material at fixation" (p. 3), they did not include conditions in which the color carrier was not at fixation. Because a correct response must be based on the carrier color, regardless of where that stimulus is located, which word is displayed in the target color may be more important than which word is located at fixation.

In Experiment 1, the color carrier was a colored bar or colored color word presented at fixation to which a vocal color naming response was required. The concern was whether presentation of a neutral word above or below the color carrier would dilute the Stroop effect. Experiment 2 was similar, except that the color carrier occurred randomly at fixation or in a position above or below fixation, with the neutral word in a neighboring position. Experiments 3 and 4 were similar to Experiments 1 and 2, except that the color carrier was a colored neutral word or color bar. Experiment 5A used similar displays to those of Experiments 3 and 4, but with display duration varied to evaluate whether attention shifts to the color word in the nontarget location after being directed initially to the location of the color carrier stimulus. Experiment 5B was a control experiment in which display duration was varied as in Experiment 5A, but with the color carrier being the color word.

Experiment 1

Experiment 1 was designed to examine whether the Stroop dilution effect occurred when the color word was the color carrier that was always presented at fixation. The target color at fixation was presented in a color bar or integrated with a color word that was congruent or incongruent with the color. On some trials, a neutral word printed in white was presented above or below the target stimulus (see Figure 1).

Because the color carrier always appeared at fixation, participants presumably attended to that location. If word recognition is a serial process, as Kahneman and Chajczyk (1983) suggested, the color word at fixation should always capture attention and the neutral word in a nontarget location should not. Consequently, no Stroop dilution should occur. On the other hand, if visual interference occurs at preattentive perceptual processes, as suggested by Brown et al. (1995), then a Stroop dilution effect should be found.

Mitterer et al.'s (2003) unlimited-capacity account also predicts that Stroop dilution will be found in Experiment 1, because all visual transients are assumed to lead to attention-capture processes. Consequently, the size of the Stroop effect should be

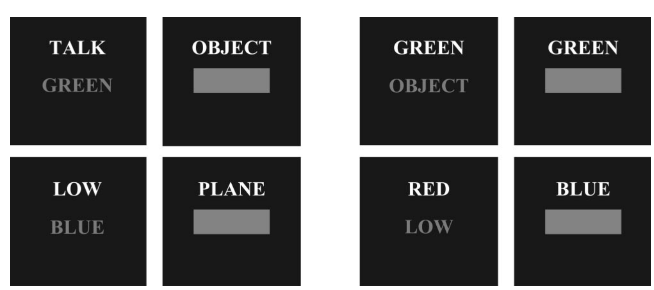

Figure 1. Example stimuli used in Experiments 1 and 2 (left two columns) and 3 and 4 (right two columns). The target color for all displays is green, depicted in the figure by gray. Within each pair of columns, the left column depicts a stimulus for which the target color was conveyed as a dimension of a word and the right column depicts a stimulus for which the target color was conveyed in a rectangle. For conditions that included a color word, the top row depicts a congruent relation with the color and the bottom row an incongruent relation.

reduced by the onset of a neutral word even when the color word is integrated with the target color at fixation.

Method

Participants. Sixteen undergraduate students enrolled in introductory psychology participated in partial fulfillment of a course requirement. All were fluent English speakers and had normal or corrected-to-normal visual acuity and color vision.

Stimuli and apparatus. Stimuli were presented on the display screen (17 in.) of a personal computer, viewed at a distance of approximately 60 cm. The color word "blue," "green, " "red, " or "yellow" was spoken into a microphone interfaced with the computer. The microphone was placed at the participant's sagittal midline. The spoken responses were categorized by Microsoft Speech Application SDK 5.1.

The carrier stimulus, presented at the center of the screen, was a bar (3.9 cm × 0.8 cm) or color word (in uppercase letters) BLUE (1.8 cm × 0.8 cm), GREEN (2.6 cm × 0.8 cm), RED (1.4 cm × 0.8 cm), and YELLOW (2.9 × 0.8 cm) presented in a blue, green, red, or yellow color. On 80% of the trials, the target stimulus was accompanied by a neutral word, presented in white uppercase letters, above or below it. The distance between the target stimulus and the neutral word was 0.6 cm. Four neutral words, TALK (1.8 cm × 0.8 cm), PLANE (2.5 cm × 0.8 cm), LOW (1.6 cm × 0.8 cm), and OBJECT (2.9 cm, x 0.8 cm), were selected on the basis of word frequency and length to correspond roughly to the frequency and length of the color words.

A total of 400 test trials was presented. These were composed from the 5 Carriers (bar or word RED, BLUE, GREEN, YELLOW) x 4 Colors (red, blue, green, yellow) x 5 Distractors (no distractor and each of the four neutral words), for a total of 100 trials times 4 replications. The trial types were randomized within the 400 total trials. With this procedure, the color carrier was a bar on 20% of the trials and a color word on 80%; each was presented alone on 20% of the trials and with a neutral word on 80% of the trials. When the target stimulus was a color word, the word was congruent with the color on 25% of the trials and incongruent on 75%.

Procedure. Participants were tested individually in a dark room. Each participant performed a 40-trial practice block prior to the 400 test trials, which were divided into five 80-trial blocks, each of which was self-initiated when the participant was ready (typically, immediately after the prior block ended) by clicking on a computer mouse. Each trial began with a fixation point, which was a plus sign (0.5 cm × 0.6 cm) that appeared at the center of the screen for 500 ms. The screen then went blank for 800 ms. Participants were told to stare at the fixation point while it was present and to maintain fixation on that location during the blank interval. A masking display, consisting of three rows of six *X* characters each centered at the fixation location, was displayed for 250 ms, followed immediately by the target display for 250 ms, and then the masking display again for another 250 ms (see Figure 2). The masking display occupied the rows where the carrier stimulus and neutral word could occur and ensured that the effective duration of the target display matched the physical duration. Participants were instructed to name the color of the target stimulus by saying "blue," "green, " "red, " or "yellow." After a response, visual feedback (correct, incorrect, or unclear) was provided for 300 ms. The plus sign for the next trial appeared 1,200 ms after the offset of the feedback.

Results

Trials with reaction times (RTs) shorter than 100 ms or longer than 2,000 ms were removed as outliers, as were those for which the response was unclear, which resulted in 3.33% of the trials being excluded. Mean RT and percentage error (PE) were calculated for each participant as a function of color carrier (congruent word, incongruent word, or bar) and distractor neutral word (distractor and no distractor). Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 1).

RT. The main effect of distractor was not significant, $F(1, 15) = 2.08$, $p = .1694$, $MSE = 216$. Mean RT for the condition in which a neutral word was presented along with the color-carrier stimulus ($M = 583$ ms) was similar to that for the condition in which no neutral word was presented ($M = 579$ ms). The main effect of color carrier was significant, $F(2, 30) = 84.21$, $p < .0001$, $MSE = 1{,}706$. Mean RT was shortest when the color carrier was a bar ($M = 534$ ms), a little longer when it was a congruent color word ($M = 552$ ms), and much longer when it was an incongruent color word ($M = 658$ ms). That is, a 106-ms Stroop effect (RT for the incongruent condition minus RT for the congruent condition) occurred. A Scheffé test showed that the responses were significantly longer for incongruent words than for congruent words or color bars. Most important, the interaction of distractor and carrier was not significant, $F(2, 30) < 1.0$. The Stroop effect was 106 ms regardless of whether a neutral-word distractor word was present or not.

PE. There was no main effect of distractor, $F(1, 15) < 1.0$. PE was 3.12% for trials without a distractor word and 3.08% for trials with a distractor word. As in the RT data, the main effect of color carrier was significant, $F(2, 30) = 6.42$, $p = .0048$, $MSE = 35.56$. PE was lowest when the color carrier was a bar ($PE = 1.37\%$), a little higher when it was a congruent word ($PE = 1.76\%$), and highest when it was an incongruent word ($PE = 6.18\%$). A Stroop effect of 4.42% on PE was found. The interaction of distractor and color carrier was not significant, $F(2, 30) < 1.0$, indicating that the magnitude of Stroop effect did not differ statistically between trials with a distractor word (4.17%) and without one (4.67%).

Discussion

When the color carrier was a color word, a Stroop effect of 106 ms was found, as is typical of studies that use color words mapped to vocal responses (see, e.g., MacLeod, 1991). More important, a

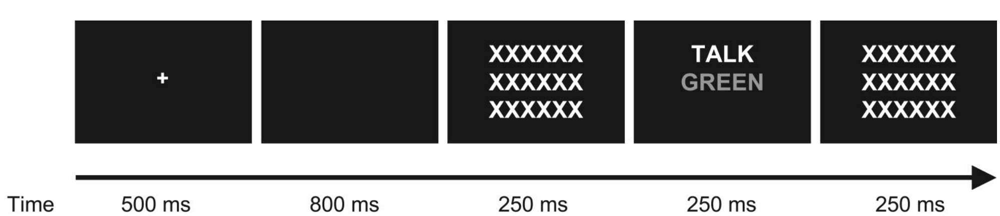

Figure 2. Example trial sequence for Experiment 1. The target color for all displays is red, depicted in the figure by gray.

Table 1
Mean Reaction Time (in Milliseconds) and Percentage of Error as a Function of Distractor and Color Carrier in Experiment 1 and Those Variables and Target Location in Experiment 2

Distractor	Color carrier: Congruent	Incongruent	Bar	Stroop effect
Experiment 1				
No distractor	552 (1.95)	658 (6.12)	527 (1.30)	106 (4.17)
Neutral word	552 (1.57)	658 (6.24)	541 (1.42)	106 (4.67)
Experiment 2				
Target location				
Central				
No distractor	630 (3.91)	718 (4.19)	586 (0.78)	88 (0.28)
Neutral word	627 (2.34)	734 (4.65)	603 (1.38)	107 (2.31)
Peripheral				
No distractor	630 (0.78)	746 (4.51)	607 (4.02)	116 (3.73)
Neutral word	625 (2.37)	760 (4.25)	616 (2.16)	135 (1.88)

neutral word displayed above or below the color word had no influence on the Stroop effect. This finding resembles that obtained in Roberts and Besner's (2005) Experiment 5, which was similar to Experiment 1 in many respects except for the use of manual keypresses rather than vocal color-naming responses. The absence of a Stroop dilution effect is consistent with the prediction of Kahneman and Chajczyk's (1983) attentional capture account, because that account implies that attention is directed initially to the colored stimulus, which is also the color word on the Stroop trials of Experiment 1.

The early visual interference account incorrectly predicts that Stroop dilution should be present because the processing of the visual features for words is automatic. This prediction is in agreement with the interpretation that Brown et al. (1995) provided for the Stroop dilution effect they obtained when the color word was at fixation and a relevant color bar and neutral word were at more peripheral locations. However, Brown et al. also suggested in their General Discussion that when the target stimulus is presented at attended locations, it may be "processed in a 'protected' mode that largely prevents interference at the early visual processing stage from distractor stimuli with the same type of feature content presented nearby" (p. 1409). If one makes this ad hoc assumption that the color word, even though irrelevant to the task, was processed in a protected mode because it was a feature of the color-carrier stimulus in our Experiment 1, then it is possible to maintain the early visual interference account.

The unlimited-capacity account also did not predict the absence of the Stroop dilution effect. As described in the introduction, Mitterer et al. (2003) emphasized that the critical factor in their account is that the neutral word provides an additional visual transient and because of this fact will compete with the color word for attentional capture. Because their emphasis is on competing transients and not on how or where those are presented, their account would seem to predict a typical Stroop dilution effect. One might suggest that the color word preferentially captured attention over the distractor, because attention was focused at the fixation location where the color carrier would appear. However, Mitterer et al. dismissed the possibility that attention could be maintained at fixation for 1 s or longer when evaluating Brown et al.'s (1995) results. It also might be suggested that the mask that appeared immediately before the target display acted as a location cue, much as the rectangle did in Mitterer et al.'s Experiment 2. However, the mask covered the entire area in which the color-carrier stimulus and distractor occurred, rather than outlining the location of the color carrier, and is unlikely to have directed attention to the color word.

Experiment 2

In contrast to Mitterer et al.'s (2003) reasoning that attention cannot be maintained at fixation, Roberts and Besner (2005) concluded that "processing of the distractor color word, as indexed by the Stroop effect, is dependent on the nature of the material at fixation" (p. 11). From this view, the absence of Stroop dilution in Experiment 1 could be a consequence of the color word capturing attention, to the exclusion of the neutral word, because it was part of the material at fixation. Alternatively, the absence of Stroop dilution could be a consequence of attention always being captured by the stimulus that carried the relevant target color. To distinguish between these possibilities, Experiment 2 was designed to replicate Experiment 1 but with the location of the color-carrier stimulus uncertain. The stimulus could appear at the fixation point, above the fixation point, or below it. When the color carrier appeared at fixation, the neutral word appeared above or below the carrier, as in Experiment 1. But, when the color carrier appeared above or below the fixation point, the neutral word was displayed at the fixation point.

If the color carrier always captures attention because of its relevant color feature, then Stroop dilution should not occur even when the neutral word appears at fixation and the color word that carries the color is located more peripherally. For the early visual interference account, the most straightforward prediction is that Stroop dilution should be observed in all cases, although the dilution effect might be larger when the neutral word occurs at fixation and the colored color word above or below it than when the locations are reversed, due to acuity factors.

Method

Sixteen new participants from the same pool as Experiment 1 participated to fulfill a course requirement. The apparatus, stimuli, and procedures were identical to Experiment 1, except as noted. The color-carrier stimulus was presented at one of three possible locations, the fixation point (central) and immediately above (upper) or below (lower) the fixation point, in blue, green, red, or yellow color. The neutral word distractor was presented at another adjacent location in white-colored uppercase letters on a dark background. That is, when the color carrier was presented at the fixation point, the distractor was presented above or below the carrier stimulus, and when the color carrier was presented above or below the fixation point, the distractor was presented at the fixation point. The color-carrier stimulus was presented at the central location on half of the trials and at the upper or lower location (peripheral) on the other half. As in Experiment 1, the instructions emphasized attending to the central location designated by the fixation point and maintaining attention at that location during the interval prior to presentation of the target stimulus.

Results

There were 0.20% of the trials removed from analysis using the same RT cutoff criteria as in Experiment 1. Mean RT and PE were calculated for each participant as a function of color carrier (congruent color word, incongruent color word, and color bar), distractor (neutral word and no distractor), and carrier location (central and peripheral). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 1).

RT. Carrier location influenced RT, $F(1, 15) = 10.90$, $p = .0048$, $MSE = 925$. RT was shorter when the color carrier appeared at the central location ($M = 650$ ms) than when it was presented at an upper or lower location ($M = 664$ ms). More specific analyses indicated that this location effect was significant when the carrier stimulus was a color bar, $F(1, 15) = 5.65$, $p = .031$, as well as when it was a color word, $F(1, 15) = 9.33$, $p = .008$. The main effect of distractor approached significance, $F(1, 15) = 3.81$, $p = .0698$, indicating that the presence of a neutral word distractor tended to lengthen RT (661 ms when a neutral word was present vs. 653 ms when one was not). Again, this tendency was evident for both the color-bar and color-word carriers, though it did not attain the .05 level for either carrier type when analyzed alone.

The main effect of color carrier was significant, $F(2, 30) = 123.77$, $p < .0001$, $MSE = 2{,}958$, with RT being shortest when the color carrier was a bar ($M = 604$ ms), a little longer when it was a congruent color word ($M = 628$ ms), and longest when it was an incongruent color word ($M = 740$ ms). That is, a 112-ms Stroop effect was found. A Scheffé test showed that the responses were significantly longer when the carrier stimulus was an incongruent word than when it was a congruent word or bar. Carrier interacted with carrier location, $F(2, 30) = 3.78$, $p = .0344$, $MSE = 837$. The Stroop effect was smaller when the color carrier was presented at the central location (98 ms) than when it was presented above or below that location (125 ms).

The interaction of distractor and color carrier was not significant, $F(2, 30) = 2.39$, $p = .1093$, $MSE = 725$, although it approached the .05 level when the color bar was excluded from analysis, $F(1, 15) = 4.37$, $p = .054$. Note, though, that this interaction does not indicate a Stroop dilution effect. Rather, the magnitude of the Stroop effect tended to be larger when a neutral distractor word was present (121 ms) than when one was not (102 ms). The three-way interaction of color carrier, distractor, and carrier location was not significant, $F(4, 60) < 1.0$, indicating that a similar result pattern was evident when the color carrier occurred at fixation as when the color word occurred at one of the two outer locations.

PE. Overall PE was 2.95%. The main effect of color carrier was significant, $F(2, 30) = 5.99$, $p = .0065$, $MSE = 17.16$. PE was low when the carrier stimulus was a bar (2.08%) or a congruent color word (2.35%) but was higher when the stimulus was an incongruent color word (4.40%). That is, a Stroop effect of 2.05% was found. The interaction of color carrier and carrier location was also significant, $F(2, 30) = 5.46$, $p = .0095$, $MSE = 9.35$. The Stroop effect was smaller when the color carrier was presented at the central location (1.29%) than when it was presented at the peripheral location (2.80%), consistent with the RT data. The three-way interaction of color carrier, distractor, and carrier location was significant, $F(2, 30) = 3.51$, $p = .0426$, $MSE = 9.38$. At the central target location, the Stroop effect was smaller when no neutral word was presented (0.28%) than when a neutral word was presented (2.31%). However, at the upper and lower locations, the opposite pattern was obtained (3.73% and 1.88%, respectively).

Discussion

Experiment 2 replicated the finding of Experiment 1—no Stroop dilution effect when the colored color word was presented at fixation and the neutral word was presented above or below it. Moreover, no Stroop dilution effect was evident when the positions of the words were reversed such that the neutral word occurred at fixation and the colored color word was above or below it. The absence of a Stroop dilution effect again is contrary to the most straightforward interpretation of the early visual interference account, which predicts that the features of the neutral word should have degraded the features of the color word, reducing the Stroop effect.

If the nature of the material appearing at fixation were crucial to the Stroop dilution effect, as Roberts and Besner (2005) suggested, then when the neutral stimulus appeared at the central location it should have captured attention, competed with the color word (as the unlimited-capacity and the attentional capture accounts suggest), and diluted the Stroop effect. Contrary to this prediction, there was no Stroop dilution, regardless of whether the neutral word appeared at fixation and the color carrier at a more peripheral location or vice versa.

RT to the color bar was lengthened when it was at a peripheral location, regardless of whether it was presented alone or with a neutral word. This lengthening of RT at the peripheral locations was accompanied by a larger Stroop effect when the color carrier was a color word, suggesting that the additional time to respond to the color allowed prolonged processing of the color-word name. The neutral word distractor had a similar effect, although slightly weaker, of tending to increase both overall RT and the size of the Stroop effect. These results suggest that although the target color feature directed attention to the color carrier, it took somewhat longer for this to occur when the color carrier occurred at a peripheral location and when the neutral word was also present. This additional time required to direct attention to the target color apparently allows the color word to intrude more on performance.

Experiment 3

In Experiments 1 and 2, the target color was integrated with the color word on most of the trials but never with the neutral word. In Experiment 3, the target color (always presented at fixation) was integrated with the neutral word on most trials but never with the color word (see Figure 1). When an irrelevant color word was present, it always appeared above or below the target stimulus. We aimed to determine whether a Stroop effect is evident when the color word is presented at the nontarget location and, if so, whether the effect is diluted with a neutral word color carrier.

If attention is always fully captured by the neutral word at the target location, then the color word at a peripheral location should produce no Stroop effect. In other words, we should observe complete dilution of the Stroop effect. Roberts and Besner (2005; Experiments 2 and 9) obtained this result with keypresses, for which the dimensional overlap, or association, with color words is not as strong as it is for spoken color names (Lu & Proctor, 2001; O'Leary & Barber, 1993). Thus, the possibility exists that the color word could still produce a significant Stroop effect with color-naming responses. In contrast, the unlimited-capacity account predicts no Stroop dilution in Experiment 3. The automatic component of the Stroop effect should not differ as a function of whether the target is a color bar or a neutral word. The other possible source of the Stroop effect, attentional capture by the color word, also should not differ across the two conditions because there are two transients (the color carrier and the distractor color word) for all trials on which a distractor color word appears. Thus, the attention capture by the color word should be roughly equal in the two conditions.

Method

Sixteen new participants from the same pool as Experiments 1 and 2 participated in Experiment 3. They satisfied the same restrictions as for Experiments 1 and 2. The apparatus, stimuli, and procedures were identical to Experiment 1, except that the color-carrier stimulus was either a bar or one of the neutral words, TALK, PLANE, LOW, and OBJECT, and the distractor was a congruent or incongruent color word. The target stimulus was presented in blue, green, red, or yellow color and the distractor word, BLUE, GREEN, RED, or YELLOW, was presented in white. Participants were asked to name the color of the carrier stimulus by saying "blue," "green, " "red, " or "yellow."

Results

There were 0.66% of the trials omitted from analysis using the same RT cutoff criteria as in Experiments 1 and 2. Mean RT and PE were calculated for each participant as a function of color carrier (neutral word and color bar) and distractor (congruent color word, incongruent color word, and no distractor). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 2).

RT. Responses were faster when the color carrier was a bar (M = 501 ms) than when it was a neutral word (M = 535 ms), $F(1, 15) = 64.49$, $p < .0001$, $MSE = 436$. The main effect of distractor was significant, $F(2, 30) = 28.36$, $p < .0001$, $MSE = 895$. RT was shortest when the distractor was a congruent word (M = 493 ms), intermediate when no distractor was presented (M = 512 ms), and longest when distractor was an incongruent word (M = 548 ms). That is, naming the color of the carrier stimulus was facilitated by a congruent color word and was interfered with by an incongruent color word. This 55-ms Stroop effect was modulated by color carrier, $F(2, 30) = 10.26$, $p = .0004$, $MSE = 575$, indicating that Stroop dilution occurred. The Stroop effect was 79 ms (468 ms and 547 ms for congruent and incongruent color words, respectively) when the color-carrier stimulus was a bar but only 32 ms (518 ms and 550 ms, respectively) when it was a neutral word. An additional analysis showed that this latter difference was still significant, $F(2, 30) = 7.15$, $p = .0029$, $MSE = 575$, and a Scheffé test showed that a significant Stroop effect was found. Without a distractor word, mean RT was 488 ms when the color carrier was a bar and 537 ms when it was a neutral word.

PE. No main effect of color carrier occurred, $F(1, 15) < 1.0$, even though PE tended to be lower with neutral word stimuli (PE = 1.29%) than with color-bar stimuli (PE = 1.61%). A Stroop effect was obtained, $F(2, 30) = 4.19$, $p = .0248$, $MSE = 3.59$. When no distractor word was presented, PE was 1.81%. However, PE decreased when a congruent distractor word was presented (PE = 0.94%) and increased when an incongruent distractor word was presented (PE = 2.23%). Even though the interaction of carrier and distractor was not statistically significant, $F(2, 30) < 1.0$, the PE data also showed a tendency toward a Stroop dilution effect. A Stroop effect of 1.71% occurred when the color carrier was a bar, and it decreased to 0.87% when it was a neutral word, as in the RT data.

Table 2
Mean Reaction Time (in Milliseconds) and Percentage of Error as a Function of Color Carrier and Distractor in Experiment 3 and Those Variables and Target Location in Experiment 4

Color carrier	Distractor: Congruent	Distractor: Incongruent	Distractor: No distractor	Stroop effect
Experiment 3				
Bar	468 (0.78)	547 (2.49)	488 (1.57)	79 (1.71)
Neutral word	518 (1.10)	550 (1.97)	537 (0.80)	32 (0.87)
Experiment 4				
Target location				
Central				
Bar	541 (0.00)	620 (1.30)	526 (2.34)	79 (1.30)
Neutral word	572 (1.76)	600 (1.43)	580 (0.78)	28 (−0.33)
Peripheral				
Bar	563 (0.00)	620 (1.30)	558 (3.13)	57 (1.30)
Neutral word	596 (1.56)	624 (1.76)	591 (1.17)	28 (0.20)

Discussion

The Stroop effect obtained with the separate color bar and color word in Experiment 3 was 79 ms, which is significantly smaller than the effect of 106 ms obtained when the color word was a dimension of the color carrier in Experiment 1, $F(1, 94) = 17.31$, $p < .0001$. Despite the smaller magnitude, the Stroop effect was diluted to only 32 ms when the carrier stimulus was a neutral word. The occurrence of Stroop dilution with this stimulus arrangement is in agreement with the findings of Roberts and Besner's (2005) Experiment 2 that used keypress responses. However, whereas the Stroop effect was completely eliminated in their study, a significant effect was still evident with the vocal responses in our Experiment 3. The continued presence of the Stroop effect in Experiment 3 likely reflects stronger activation from the color words due to the greater overlap with their spoken names than with arbitrarily assigned keypresses. The smaller base Stroop effect in Experiment 3 than in Experiment 1 and the reduction in effect size by the neutral word suggest that the color word captures less attention when it is not the carrier of the target color than when it is.

The results of Experiment 3 are inconsistent with Mitterer et al.'s (2003) unlimited-capacity account, according to which the Stroop effect should have been unaffected by whether a color word competed for attentional capture with a colored neutral word or color bar. The account could be modified to allow a lower likelihood for the attentional selection of the semantic information of the color word when the color carrier was a neutral word than when it was a color word. This explanation requires the assumption that the semantic information and color information of the target stimulus were processed separately, and these separate properties and the semantic representation of the color word competed for attentional capture. Thus, there would be three properties competing for attention rather than just the two visual transients (target and distractor words). However, if this were the case, a Stroop dilution effect should have occurred in Experiment 1, because the three pieces of information should have competed for attentional capture when the target was a color word.

The results of Experiment 3 are in agreement with the prediction of the most straightforward interpretation of the early visual interference account, according to which perceptual processing of the attended neutral word at fixation should degrade perceptual feature analysis of the peripheral color word, thus reducing the Stroop effect. However, as previously noted, this interpretation also predicts Stroop dilution for the situation examined in Experiments 1 and 2, in which the target stimulus was a colored color word and the distractor stimulus a neutral word. The prediction that Stroop dilution should have occurred not only in Experiment 3 but also in Experiments 1 and 2 is derived from a basic assumption of the early visual interference account. This assumption is that "processing of visual features can interact across separate stimulus locations at a relatively early level of processing" (Brown, et al., 1995, p. 1397), which implies that the early visual interference is reciprocal in nature. According to Brown et al., the visual interference is a consequence of the complex visual pattern made up of the visual features. Thus, if the perceptual process of the distractor were degraded by the visual features of the target word in Experiment 3, it also should have been degraded in Experiment 1.

We previously noted that the absence of Stroop dilution in Experiments 1 and 2 could be accommodated by the early visual interference account by assuming that the target stimulus was processed in a "protected" mode. Application of this account to Experiment 3 would lead to the prediction of little or no Stroop effect when the target stimulus was a colored neutral word. However, it would also predict little or no Stroop effect when the target stimulus was a colored bar, unless the assumption is also made that processing of the target is in the protected mode only when it is a color word.

Experiment 4

The main findings of Experiment 1, in which the location of the color carrier was known, were replicated in Experiment 2, in which the location was unknown. Similarly, the purpose of Experiment 4 was to determine whether the main findings of Experiment 3, in which the target location was known, would be replicated when the target location was unknown.

In Experiment 4, the color-carrier stimulus (a bar or a neutral word) appeared at, above, or below the fixation point. As in Experiment 2, when the carrier appeared at the fixation point, the color word appeared above or below the carrier stimulus; when the carrier appeared above or below the fixation point, the color word appeared at the fixation point. If the stimulus that occurs at fixation takes precedence over the other stimulus, as Roberts and Besner (2005) concluded, then the baseline Stroop effect should be larger, and the Stroop dilution effect smaller, when the color word occurs at fixation and the carrier stimulus above or below it than when their positions are reversed. If, on the other hand, the critical factor is attention being drawn to the location of the carrier stimulus by its color, as the results of Experiment 2 suggested, then the Stroop effect should be of similar size regardless of whether or not the color word is at fixation.

Method

Sixteen participants from the same pool as Experiments 1–3 participated to fulfill a course requirement. The apparatus, stimuli, and procedures were identical to Experiment 3, except that the target stimulus, as in Experiment 2, was presented at one of three possible designated locations (upper, central, or lower) in blue, green, red, or yellow color, and the distractor was presented at another adjacent location in white-colored uppercase letters on a dark background.

Results

There were 0.06% of the trials removed from analysis using the same RT cutoff criteria as in Experiments 1–3. Mean RT and PE were calculated for each participant as a function of color carrier (neutral word and color bar), distractor (congruent color word, incongruent color word, and no distractor), and carrier location (central and peripheral). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 2).

RT. Carrier location affected RT, $F(1, 15) = 29.48$, $p < .0001$, $MSE = 578$. RT was shorter when the carrier appeared at the central location ($M = 573$ ms) than at a peripheral location ($M = 592$ ms). As in Experiment 3, responses were faster when the color carrier was a bar ($M = 571$ ms) than when it was a neutral word ($M = 594$ ms), $F(1, 15) = 5.24$, $p = .0370$, $MSE = 4{,}657$. Also, a Stroop effect of 48 ms was found, $F(2, 30) = 68.76$, $p < .0001$, $MSE = 784$. RT was shorter when the distractor was a congruent color word ($M = 568$ ms) than when it was an incongruent color word ($M = 616$ ms). The mean RT was 564 ms when no distractor was presented.

It is important to note that the interaction of color carrier and distractor was significant, $F(2, 30) = 11.97$, $p = .0002$, $MSE = 978$. The magnitude of the Stroop effect was 68 ms when the color carrier was a bar, whereas it was only 28 ms when the color carrier was a neutral word. Without a color-word distractor, the mean RT was 542 ms when the color carrier was a bar and 586 ms when it was a neutral word. The Stroop dilution effect did not interact significantly with carrier location, although this interaction approached statistical significance, $F(2, 30) = 3.01$, $p = .0645$, $MSE = 706$. When the color carrier appeared at the central location and the distractor color word at a peripheral location, the Stroop effect of 79 ms for the color bar was reduced to 28 ms when the color carrier was a neutral word. When the carrier appeared at a peripheral location and the color word at the central location, the Stroop effect of 57 ms for the color bar was again reduced to 28 ms when the color carrier was a neutral word.

PE. Overall PE was 1.38%. Even though PE showed a Stroop effect of 0.62%, the main effect of distractor was not significant, $F(2, 30) = 1.27$, $p = .2943$, $MSE = 13.39$. The interaction of carrier and distractor approached significance, $F(2, 30) = 3.12$, $p = .0588$, $MSE = 15.18$. As in the RT data, the Stroop effect tended to be smaller when color carrier was a neutral word (−0.06%) than when it was a bar (1.30%). No other main effect or interaction was significant, $F\text{s} < 1.0$.

Discussion

As in Experiment 3, a Stroop dilution effect was evident. The Stroop effect was larger when the distractor color word was paired with a color bar than when it was paired with a colored neutral word. Mitterer et al.'s (2003) unlimited-capacity account does not predict the Stroop dilution effect in Experiment 4 for the same reason that it did not predict an effect in Experiment 3. According to the account, the same magnitude of the Stroop effect should occur regardless of whether the attentional competition occurs between the color word and color bar or between the color word and neutral word, because the color word is equally likely to be attended in these two transient conditions.

Although RT was longer when the carrier stimulus was presented in a peripheral location and the distractor at the central location than when their positions were reversed, the baseline Stroop effect for the color bar paired with a color-word distractor tended to be smaller. If presentation of the color word at the central location allowed it to be attended more often, then the Stroop effect should have been larger. Because of the tendency toward a smaller base Stroop effect when the color carrier was at a peripheral location, the Stroop dilution effect also tended to be a bit smaller. However, the magnitude of the Stroop effect with central or peripheral presentation of the colored neutral word was identical, indicating that the residual Stroop effect does not depend on the carrier location. The relatively small influence of target location on the Stroop and Stroop dilution effects suggest that the most important factor is what word is integrated in the color carrier (where spatial attention is ultimately directed) but not where the color carrier is located.

Experiments 5A and 5B

When the color carrier was a color word in Experiments 1 and 2, the presence of a neutral-word distractor had no influence on the Stroop effect, regardless of whether the location of the color carrier was known or not. This result suggests that attention was always directed at least initially to the color word rather than the neutral word. In Experiments 3 and 4, when the color word was the separate distractor stimulus and the color carrier a color bar, the Stroop effect was smaller than when the color word was part of the carrier stimulus in Experiments 1 and 2, suggesting that attention was first directed to the color carrier and then to the color word. For those trials on which the color carrier was a neutral word, the Stroop dilution effect was obtained, regardless of whether the color-carrier location was fixed or not, although a residual Stroop effect of about 30 ms remained. This outcome is also consistent with the hypothesis that attention was directed initially to the color carrier. Because the color carrier took longer to process when it was a neutral word than when it was a bar, less time would have been available to shift attention subsequently to the color-word distractor. Thus, on the whole, these results are consistent with the hypothesis that attention was first directed to the color carrier (even when its location was unpredictable) and then shifted to the distractor if time allowed. However, Experiments 1–4 did not directly test whether a shift of attention actually occurred.

In Experiment 5A, we manipulated display duration to test whether the color word had an effect because it captured attention or because it was processed automatically. As in Experiment 3, the color carrier was a color bar or colored neutral word always presented at fixation. However, the display, which contained the color carrier and distracting color word, was presented for durations of 100, 150, 200, or 250 ms, randomly intermixed. If the Stroop effect is caused by an attentional shift to the color word following attention to the color carrier, then the effect size should decrease as display duration is reduced. This prediction is made because a briefer display allows less time to shift attention to the color word after first attending to the relevant color-carrier stimulus. In contrast, if the Stroop effect is due to automatic activation of the color-word name, it should not depend strongly on display duration.

In Experiment 5A, a briefer display could make the color word more difficult to read than a longer display, rather than allowing less time to shift attention to the color word after first attending to the color-carrier stimulus. Therefore, we conducted a control experiment (Experiment 5B) with the color word integrated in the color carrier. The display, which contained the color carrier with or without a neutral distractor word, was presented for durations of 100, 150, 200, or 250 ms, randomly intermixed, as in Experiment 5A. If the effect of display duration in Experiment 5A is mainly on the time available to shift attention to the color word after initially attending to the carrier stimulus, then the Stroop effect should not vary with display duration in Experiment 5B because the color word is always part of the initially attended carrier stimulus. However, if the primary effect of display duration is on the difficulty of reading the color word, then the Stroop effect should decrease in size at short display durations in Experiment 5B as well as in Experiment 5A.

Method

Sixteen participants from the same pool as Experiments 1–4 participated in Experiment 5A and another 16 participants in Experiment 5B to fulfill a course requirement. Except as noted below, the apparatus, stimuli, and procedures of Experiments 5A and 5B were similar to those of Experiment 3. In Experiment 5A, the color carrier, presented at fixation, was a color bar on half of the trials and a neutral word on the other half. For each color-carrier type, a color-word distractor was present on all trials, being congruent with the color on half of the trials and incongruent on the other half. Each participant performed a 24-trial practice block and two 192-trial test blocks. Unlike Experiments 1–4 in which the fixation point display was followed by a blank display, the fixation point display was followed immediately by the masking display (three rows of six *X*s flashed for 250 ms). After the offset of the masking display, the target display was presented for 100, 150, 200, or 250 ms. As in Experiments 1–4, the stimulus was followed by the masking display for 250 ms. The plus sign for the next trial appeared 1,250 ms after a 250-ms blank for a correct response and a 250-ms tone for an incorrect response.

In Experiment 5B, the color carrier, presented at fixation, was a colored congruent color word on half of the trials and a colored incongruent color word on the other half. A neutral word was presented either above or below the color carrier on half of the trials in white and no neutral word was presented on the other half of the trials. The target display was presented for 100, 150, 200, or 250 ms.

Results of Experiment 5A

There were 0.65% of the trials removed from analysis using the same RT cutoff criteria as in Experiments 1–4. Mean RT and PE were calculated for each participant as a function of color carrier (neutral word and color bar), distractor (congruent color word and incongruent color word), and display duration (100, 150, 200, and 250 ms). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 3).

Table 3
Mean Reaction Time (in Milliseconds) and Percentage of Error in Experiment 5A as a Function of Color Carrier, Distractor, and Display Duration (100, 150, 200, and 250 ms)

Color carrier and display duration	Distractor		
	Congruent	Incongruent	Stroop effect
100 ms			
Bar	541 (0.53)	586 (1.04)	45 (0.51)
Neutral word	592 (1.05)	607 (0.00)	15 (−1.05)
150 ms			
Bar	539 (0.26)	596 (1.31)	57 (1.05)
Neutral word	597 (1.07)	618 (1.04)	21 (−0.03)
200 ms			
Bar	537 (0.00)	607 (2.86)	70 (2.86)
Neutral word	617 (0.54)	637 (1.05)	20 (0.51)
250 ms			
Bar	532 (0.00)	629 (2.86)	97 (2.86)
Neutral word	610 (0.00)	638 (1.08)	28 (1.08)

RT. As in Experiments 3 and 4, RT was shorter when the color carrier was a bar (M = 571 ms) than when it was a neutral word (M = 615 ms), $F(1, 15) = 95.68$, $p = .0001$, MSE = 1,276. The main effect of display duration was significant, $F(3, 45) = 11.70$, $p = .0001$, $MSE = 526$. Mean RT increased with duration (Ms = 582, 588, 600, and 602 ms for 100, 150, 200, and 250 ms, respectively). A 44-ms Stroop effect was found, $F(1, 15) = 67.41$, $p < .0001$, $MSE = 1844$. RT was shorter when the distractor was a congruent color word (M = 571 ms) than when it was an incongruent color word (M = 615 ms).

The Stroop effect interacted with display duration (see Figure 3), $F(3, 45) = 3.78$, $p = .0169$, $MSE = 786$. The longer the display was presented, the larger the Stroop effect (30, 39, 45, and 63 ms in the magnitude for 100, 150, 200, and 250 ms, respectively). As in Experiments 3 and 4, the interaction of carrier and distractor was significant, $F(1, 15) = 27.47$, $p = .0003$, MSE = 1,514. The Stroop effect was 68 ms when the carrier stimulus was a bar, whereas it was only 21 ms when the carrier stimulus was a neutral word. This Stroop dilution effect interacted with display duration, $F(3, 45) = 2.82$, $p = .0494$, $MSE = 397$. The results of simple main effect tests showed that the Stroop effect increased significantly with display duration when the target was a color bar, $F(3, 45) = 9.70$, $p = .0001$, $MSE = 397$ (see Figure 3; 45, 57, 70, and 96 ms in the magnitude for 100, 150, 200, and 250 ms, respectively), but not when it was a neutral word, $F(3, 45) < 1.0$, $p = .6188$, $MSE = 397$ (15, 21, 21, and 28 ms, respectively). No other interactions were significant.

PE. Overall PE was 0.94%. PE also showed a significant Stroop effect of 1.01%, $F(1, 15) = 6.24$, $p = .0146$, $MSE = 10.40$. The interaction of distractor and display duration was significant, $F(3, 45) = 4.382$, $p = .0086$, $MSE = 4.30$. As in the RT data, the Stroop effect increased with display duration (−0.27%, 0.52%, 1.69%, and 2.10% for 100, 150, 200, and 250 ms, respectively). A significant Stroop dilution effect was obtained, $F(1, 15) = 4.55$, $p = .0499$, $MSE = 10.92$. The Stroop effect was 1.89% when the color carrier was a bar, but it was only 0.12% when the carrier was a neutral word. No other main effect or interaction was significant.

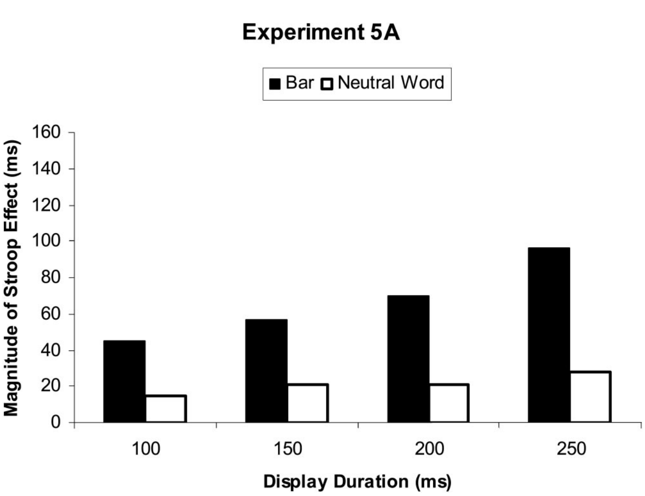

Figure 3. Magnitude of Stroop effect as a function of display duration for Experiment 5A.

Results of Experiment 5B

Using the same RT cutoff criteria as in Experiments 1–4, we removed 0.80% of the trials removed from analysis. Mean RT and PE were calculated for each participant as a function of color carrier (congruent color word and incongruent color word), distractor (no distractor and neutral word), and display duration (100, 150, 200, and 250 ms). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 4).

RT. The main effect of color carrier was significant, $F(1, 15) = 396.32$, $p < .0001$, MSE = 3,071. Mean RT was shorter when the color carrier was a congruent color word (M = 622 ms) than when it was an incongruent color word (M = 760 ms). That is, a 138 ms Stroop effect was obtained. As in Experiments 1 and 2, no Stroop dilution effect occurred. That is, the interaction of color carrier and distractor was not significant, $F(1, 15) = 3.03$, $p = .1024$, $MSE = 599$. The magnitude of the Stroop effect was 132 ms when a neutral word was present, and it was 143 ms when

Table 4
Mean Reaction Time (in Milliseconds) and Percentage of Error in Experiment 5B as a Function of Color Carrier, Distractor, and Display Duration

Distractor and display duration	Color carrier		
	Congruent	Incongruent	Stroop effect
100 ms			
No neutral word	619 (0.52)	750 (3.68)	139 (3.16)
Neutral word	626 (0.00)	773 (3.67)	147 (3.67)
150 ms			
No neutral word	621 (0.79)	761 (3.39)	140 (2.60)
Neutral word	624 (0.26)	765 (2.08)	141 (1.82)
200 ms			
No neutral word	631 (0.26)	759 (3.69)	128 (3.43)
Neutral word	620 (0.00)	760 (2.90)	140 (2.90)
250 ms			
No neutral word	624 (0.26)	754 (3.73)	130 (3.47)
Neutral word	614 (0.26)	759 (3.91)	145 (3.65)

it was absent. Most important, the Stroop effect did not interact with display duration, $F(3, 45) < 1.0$, $p = .8806$, $MSE = 493$, being 140, 140, 135, and 138 ms, respectively, for durations of 100, 150, 200, and 250 ms (see Figure 4). No other main effect or interaction was significant.

PE. Overall PE was 1.84%. As in Experiments 1–4, PE showed a significant Stroop effect of 3.09%, $F(1, 15) = 22.28$, $p = .0003$, $MSE = 27.36$. As in the RT data, this Stroop effect did not interact with distractor, $F < 1.0$. The magnitude of the Stroop effect was 3.16% when no neutral word was present and 3.01% when it was present. Most important, the interaction of color carrier and display duration was not significant, $F < 1.0$. The Stroop effect was 3.41%, 2.21%, 3.17%, and 3.56% for display durations of 100, 150, 200, and 250 ms, respectively. No other main effect or interaction was significant.

Discussion

As in Experiments 3 and 4, the Stroop effect was larger when the color carrier was a bar than when it was a neutral word in Experiment 5A. This result is not in agreement with the unlimited-capacity account, because, according to that account, the magnitude of the Stroop effect should have been roughly the same regardless of whether attentional competition occurs between the color word and color bar or between the color word and neutral word.

The Stroop effect and, consequently, the amount of Stroop dilution interacted with display duration when the color carrier was either a color bar or neutral word in Experiment 5A. The longer the display was visible, the more the color-naming performance was influenced by the color word. This result implies that the influence of the color word on performance in Experiment 5A was due to a shift of attention to the color word. With increasing display duration, attention shift to the color word was more likely to occur. If the Stroop effect were due to automatic activation of the color-word meaning, the magnitude of the effect in Experiment 5A should not have depended much on display duration. Furthermore,

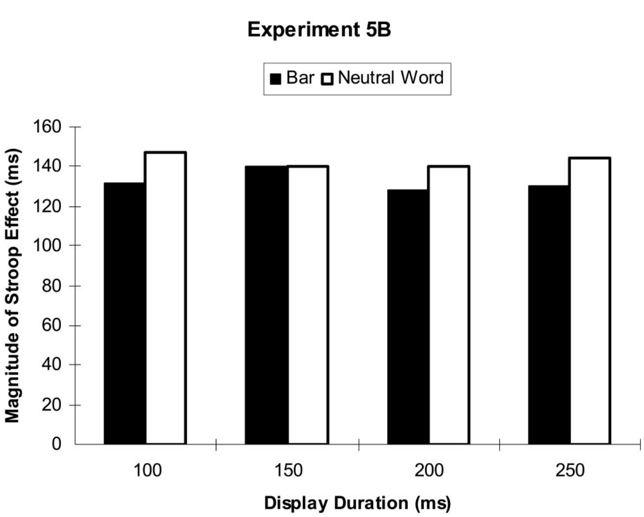

Figure 4. Magnitude of Stroop effect as a function of display duration for Experiment 5B.

the influence of display duration on the Stroop effect was much more evident when the color carrier was a bar than when it was a neutral word, being significant only in the former case. As in Experiments 3 and 4, mean RT was shorter when the color carrier was a bar than when it was a neutral word. These results imply that the attentional shift to the color word occurred more frequently when the target was a color bar than when it was a neutral word.

If the results obtained in Experiment 5A were due to increased difficulty in reading the color word as display duration decreased, rather than to less opportunity for attention shifts to the color word, the influence of the center-located color word should also have been reduced at the shorter display durations in Experiment 5B. However, when the color carrier was a color word in Experiment 5B, the Stroop effect did not vary as a function of display duration. The Stroop effect at the shortest duration of 100 ms was as large as that obtained at the longer durations. This finding suggests that the influence of display duration on the Stroop effect in Experiment 5A is on the likelihood of an attentional shift to the color word.

General Discussion

To test candidate explanations of Stroop dilution, the present study examined the Stroop dilution effect in situations in which the target color was integrated with the color word or the neutral word. The basic idea was that the word that served as the carrier of the target color should receive more attention than the objects in other locations, either because the word was at the location at which the color carrier was known to occur or because the color automatically attracted attention to its location. In Experiment 1, the target stimulus was a colored color word (or a color bar) presented at fixation. When a neutral word (in white) was presented, it appeared either above or below the target stimulus. A large Stroop effect of 106 ms was obtained for the colored color words regardless of whether the neutral word was presented (i.e., there was no Stroop dilution effect). Experiment 2 used a similar procedure, but with the color carrier appearing randomly at the center position or at a position above or below it. Again, a large Stroop effect was evident for the colored color words, and it was unaffected by the presence of a neutral word. This absence of Stroop dilution did not depend on whether the target was located centrally or at a peripheral position, indicating that presenting the color word as a feature of the color-carrier stimulus protects the Stroop effect from dilution regardless of whether the location of the color carrier is known in advance.

In Experiment 3, the color carrier was a neutral word or bar. In this case, the color word, presented in white above or below the color bar, produced a Stroop effect of 79 ms. This effect was smaller than when the color word was integrated with the color in Experiments 1 and 2, but the presence of a colored neutral word reduced the Stroop effect further to 32 ms. This Stroop dilution effect also was evident in Experiment 4 when the color carrier could appear in any of three locations. In Experiment 4, the distractor color word produced a Stroop effect of 68 ms when the carrier stimulus was a color bar, but it was reduced to 28 ms when the color carrier was a neutral word. In Experiments 3 and 4, dilution of the Stroop effect from the color word was just as strong when the color word was presented at fixation as when the color word was presented peripherally. This finding again indicates that the critical factor for Stroop dilution is that the neutral word is a feature of the color carrier and the color word is located in a nontarget location but not where the color carrier is located. Thus, processing priority is not necessarily given to the stimulus that occurs at fixation but instead to the stimulus that conveys the target color.

This important point is in agreement with recent evidence reported by Ansorge, Horstmann, and Carbone (2005) for top-down contingent capture by color in a choice reaction task. In their study, participants made a left or right keypress to indicate whether a line inside of a target semidisk was vertical or horizontal. The target semidisk was red on half of the trials and white on the other half. A simultaneously presented nontarget semidisk, with no line inside of it, was green on those trials for which the target was red and red on those trials for which the target was white. The RT data showed that the "better-matching" nontarget in the relevant red color captured spatial attention more strongly than did the "less-matching" nontarget in the irrelevant green color, even for the fastest responses in the RT distribution. Ansorge et al. interpreted their results as indicating that "participants specified their control settings for capture of spatial attention by the target colors in advance of the displays, so that a better-matching nontarget captured more attention than a less-matching nontarget, *right from its onset* [italics added]" (p. 254).

Experiment 5A used a procedure similar to that of Experiment 3, but with display durations ranging from 100 ms to 250 ms. The major finding was that the Stroop effect produced by a distractor color word on responses to a color bar decreased as display duration decreased. This result suggests that the color word received less attention at the short than long durations. For trials on which the color carrier was a neutral word, the Stroop effect also tended to decrease as display duration decreased, but this reduction was not statistically significant. Experiment 5B, in which the color word was integrated in the center-located color carrier, showed no decrease in the Stroop effect as display duration decreased. This outcome is consistent with the attention-shift account of the duration effect in Experiment 5A, because, in Experiment 5B, the color word should have been attended initially. The lack of effect of display duration in Experiment 5B also provides evidence that the decrease in the Stroop effect at the short durations in Experiment 5A was not due to lack of readability.

Early Visual Interference Account

The combined results of all of the experiments are difficult to reconcile with Brown et al.'s (1995) early visual interference account of the Stroop dilution effect. According to their account, the color word and neutral word are processed in parallel, but the features of each word interfere with each other. Consequently, the color word is processed less efficiently and produces a smaller Stroop effect than when it is presented without the neutral word.

The results of Experiments 1 and 2 did not show any Stroop dilution effect, suggesting that the features of the neutral word did not interfere with the perceptual processing of the color word. One could argue that the dilution effect was absent in Experiment 1 because the feature processing of the peripheral neutral word was insufficient to interfere with that of the centrally located colored color word. If this were the case, the Stroop dilution effect should be present when the neutral word is displayed at the central location and the colored color word displayed more peripherally. Yet, in Experiment 2, the Stroop dilution effect was not evident regardless of whether the neutral word was at the centered position and the colored color word was located more peripherally or vice versa. The results of Experiment 2 thus indicate that the failure of the neutral word to dilute the Stroop effect is not due to greater acuity, or to greater processing priority, at the central location than at the peripheral locations.

Brown et al. (1995) suggested that it might be possible to process a target stimulus in a mode that protects it from perceptual interference from another word, which could explain the absence of Stroop dilution effect in Experiments 1 and 2. This protected mode account implies that processing of a neutral word in the target color also should be protected from a separate color word. If so, there should have been a complete absence of the Stroop effect in the conditions of Experiments 3 and 4 in which the target colored neutral word was accompanied by a color word. Yet, even though the Stroop effect was diluted in those experiments, it was still significant. Thus, a word's being part of the color carrier does not protect the word itself, at least entirely, from effects of another word.

Lavie, Hirst, de Fockert, and Viding (2004) have proposed more generally that interference from irrelevant visual information is reduced under conditions of high perceptual load. As with Brown et al.'s (1995) specific visual interference account for the Stroop dilution effect, it is difficult to account for the results of Experiments 1–4 in terms of perceptual load, because perceptual load was similar in the experiments that produced Stroop dilution and in those that did not. On the whole, early visual interference, or perceptual load, does not seem to provide a viable explanation of the present findings.

Kahneman and Chajzyk's Attentional Capture Account

If the early visual interference account of the Stroop dilution effect is ruled out, which evidence seems to warrant, attentional capture is left as the likely cause. According to Kahneman and Chajczyk's (1983) attentional capture account, competition occurs between the color word and neutral word, with the word that captures attention being identified at the expense of the other word. The fact that the neutral word did not produce a Stroop dilution effect in Experiments 1 and 2 when the color word was a feature of the color-carrier stimulus can be attributed to attention always being directed initially to the color word, resulting in the neutral word not being identified. Note, though, that the absence of an irrelevant-word effect on a trial does not necessarily indicate that it was not identified (see, e.g., Catena, Fuentes, & Tudela, 2002; Marí-Beffa, Estévez, & Danziger, 2000). Because the color word did not have to be presented at the central location for the Stroop dilution effect to be absent, the direction of attention to the color word apparently is accomplished preattentively on the basis of the target color feature it possesses.

Such an account seems to imply that when the neutral word is a feature of the target stimulus, as in Experiments 3 and 4, attention should be captured by it on all trials, resulting in a complete absence of the Stroop effect. Yet, as noted, a significant Stroop effect still occurred. There are two possible ways to explain this fact within the context of the attentional capture account. The first is that because the names of the color words are members of the response set, processing of those words is primed (see, e.g., Proctor, 1978). Consequently, on a certain percentage of the trials, attention is directed to the color word instead of the neutral word, even though the neutral word is displayed in the target color. The fact that Roberts and Besner (2005) found the Stroop effect to be completely eliminated under similar conditions when the responses were keypresses is consistent with this account. The second possible explanation is that the neutral word is always attended to first, but processing of it is completed sufficiently quickly to allow attention to shift to the color word before a response to the target color has been made (see Lachter, Forster, & Ruthruff, 2004, for discussion of different types of attentional shifts). The results of Experiment 5 provide some evidence that this indeed may be occurring.

Mitterer et al.'s Unlimited-Capacity Attention-Capture Account

Mitterer et al.'s (2003) unlimited-capacity attention-capture account of the Stroop dilution effect differs from Kahneman and Chajczyk's (1983) account in two important ways: All words are identified in parallel and produce automatic activation, and competition for attention occurs between all visual transients, including the color bar as well as any color words. Because the color word produces automatic activation in all cases, a Stroop effect should always be evident, though it may vary in magnitude. This prediction is consistent with the fact that the color word did indeed produce a Stroop effect in all conditions of the present experiments.

However, Mitterer et al.'s (2003) account does not predict the obtained differences in relative magnitude of the Stroop effect across conditions because of the assumption that "all visual transients (e.g., sudden onsets) lead to attention capture processes" (p. 32). This assumption implies, as does Mitterer et al.'s discussion of it, that the neutral word in Experiments 1 and 2 should have competed for attentional capture and thus produced Stroop dilution. This is because only a single visual transient occurred for trials on which the colored color word was presented alone, but two transients occurred when the neutral word was added to the display. The absence of a Stroop dilution effect in Experiments 1 and 2 therefore is inconsistent with the assumption that all transients compete for attention. The account also predicts that no Stroop dilution effect should have been evident in Experiments 3 and 4, whereas it was, because the distractor color word was always paired with one other visual transient, the color bar or the colored neutral word, which means that two visual transients were present on all trials. Because the account does not distinguish between a word and nonword transient, the Stroop effect should have been equally evident for both types of target stimuli. Thus, the assumption made by Mitterer et al. that all visual transients compete equally for attention is not supported in the present study.

Constraints on Attentional Capture Accounts

From the preceding discussion, it is apparent that the present results place constraints on attentional capture accounts. First, Mitterer et al.'s (2003) assumption that all visual transients are equal is not consistent with the results. A neutral word competes with a color word for attention more than does a color bar. Second, when one word includes the target color as a feature and the other does not, attention is directed to the word with the color feature, regardless of where that word occurs in the array. Third, the fact that a color word still produces a Stroop effect when the neutral word is in the target color, but a neutral word does not produce dilution of the Stroop effect when the color word is in the target color, must be accommodated. One possible explanation is that attention is always captured by the word in the target color, but, as proposed by Mitterer et al., even unattended words are identified. Automatic activation produced by the color word produces a Stroop effect alone that is smaller than that obtained when attention is directed to the word. Because the identity of the neutral word is not related to the task being performed, the neutral word has no impact on the Stroop effect unless it is attended. Alternatively, the words may not be identified automatically, but, as indicated by Kahneman and Chajczyk (1983), when the neutral word is in the target color, attention is shifted to the color word after first being captured by the carrier stimulus. The decreasing Stroop effect as display duration decreased in Experiment 5A provides evidence for this attention shift account, although the fact that a Stroop effect remains at the shortest duration suggests that an automatic component may contribute to the effect as well. However, the fact that the Stroop effect was only 15 ms for the 100-ms exposure of a neutral-word color carrier and color-word distractor, with a nonsignificant error-rate difference in the opposite direction, suggests that any such contribution is small.

References

Ansorge, U., Horstmann, G., & Carbone, E. (2005). Top-down contingent capture by color: Evidence from RT distribution analyses in a manual choice reaction task. *Acta Psychologica, 120,* 243–266.

Baldo, J. V., Shimamura, A. P., & Prinzmetal, W. (1998). Mapping symbols to response modalities: Interference effects on Stroop-like tasks. *Perception & Psychophysics, 60,* 427–437.

Brown, T. L., Roos-Gilbert, L., & Carr, T. H. (1995). Automaticity and word perception: Evidence from Stroop and Stroop dilution effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1395–1411.

Catena, A., Fuentes, L. J., & Tudela, P. (2002). Priming and interference effects can be dissociated in the Stroop task: New evidence in favor of the automaticity of word recognition. *Psychonomic Bulletin & Review, 9,* 113–118.

Gatti, S. V., & Egeth, H. E. (1978). Failure of spatial selectivity in vision. *Bulletin of the Psychonomic Society, 11,* 181–184.

Kahneman, D., & Chajczyk, D. (1983). Tests of the automaticity of reading: Dilution of Stroop effects by color-irrelevant stimuli. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 497–509.

Kornblum, S. (1992). Dimensional overlap and dimensional relevance in stimulus-response and stimulus-stimulus compatibility. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior II* (pp. 743–777). Amsterdam: North-Holland.

Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty years after Broadbent: Still no identification without attention. *Psychological Review, 111,* 880–913.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133,* 339–354.

Lu, C.-H., & Proctor, R. W. (2001). Influence of irrelevant information on human performance: Effects of S-R association strength and relative timing. *Quarterly Journal of Experimental Psychology, 54A,* 95–136.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163–203.

Marí-Beffa, P., Estévez, A., & Danziger, S. (2000). Stroop interference and negative priming: Problems with inferences from null results. *Psychonomic Bulletin & Review, 7,* 499–503.

Mitterer, H., La Heij, W., & Van der Heijden, A. H. C. (2003). Stroop dilution but not word-processing dilution: Evidence for attention capture. *Psychological Research, 67,* 30–42.

O'Leary, M. J., & Barber, P. J. (1993). Interference effects in the Stroop and Simon paradigms. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 830–844.

Proctor, R. W. (1978). Sources of color-word interference in the Stroop color naming task. *Perception & Psychophysics, 23,* 413–419.

Risko, E. F., Stolz, J. A., & Besner, D. (2005). Basic processes in reading: Is visual word recognition obligatory? *Psychonomic Bulletin & Review, 12,* 119–124.

Roberts, M. A., & Besner, D. (2005). Stroop dilution revisited: Evidence for domain-specific, limited-capacity processing. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 3–13.

Stroop, J. R. (1935). Studies of interference in serial verbal reaction. *Journal of Experimental Psychology, 18,* 643–662.

Yee, P. L., & Hunt, E. (1991). Individual difference in Stroop dilution: Tests of the attention-capture hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 715–725.

Received March 2, 2005
Revision received January 11, 2006
Accepted January 18, 2006 ■