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ORIGINAL ARTICLE

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Stroop dilution but not word-processing dilution: evidence for attention capture

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Abstract Stroop dilution refers to the observation that the impact of a color word on the naming of a color bar is reduced if another word-like object is displayed simultaneously. Recently, Brown, Roos-Gilbert, and Carr (1995) concluded that Stroop dilution is due to early-visual interference. This conclusion was evaluated in three experiments. Experiment 1 showed that, contrary to the predictions of an early-visual interference account, (a) diluters that are similar in terms of visual complexity induced different amounts of dilution and (b) the size of the dilution effect is proportional to the size of the Stroop interference effect when the diluters are used as single distractors. Experiments 2 and 3 revealed that when the position of the color bar is pre-cued, Stroop dilution disappears. We argue that these findings support Van der Heijden's (1992) attention-capture account of Stroop dilution.

Introduction

The question whether the human information-processing system can handle all the information that it receives via its sense organs has often been investigated by means of modified Stroop tasks. In the classical Stroop task (Stroop, 1935/1992), participants have to name the color of colored color words. If the color word does not denote the color of its print (e.g., the word BLUE in red ink), the naming latencies are longer than in a neutral condition (e.g., a series of Xs in red ink) and in the congruent condition (e.g., the word RED in red ink). In a modified version of the Stroop task, the color and word are spatially separated. Participants have to name the color of a colored bar and have to ignore a distant color word. Despite the spatial separation of color and word, Stroop interference is still obtained (see, e.g., Dyer, 1973; Gatti & Egeth, 1978; Hagenaar & Van der Heijden, 1986; Merikle & Gorewitch, 1979). Because in this modified Stroop task, attention has to be directed to the position of the color, and away from the position of the word, this observation seems at variance with the assumption that the information processing system has a limited capacity. Instead, it suggests that word recognition occurs irrespective of attention and irrespective of the simultaneous processing of the target color.

The conclusion that word recognition is independent of attention has been questioned, however. Kahneman and Treisman (1984) argued that the limited-capacity view is supported by the finding that the interference of color words in the modified Stroop task can be reduced or even eliminated (Kahneman & Chajczyk, 1983; Kahneman & Henik, 1981). More recently, the observation of reduced interference in modified Stroop tasks (Stroop dilution) has been used by Brown, Roos-Gilbert, and Carr (1995) to argue for the existence of an early bottleneck in visual recognition, called early-visual interference.

In our view, however, these lines of reasoning are subject to a logical error: affirming the consequence (cf. Driver & Tipper, 1989, p.305). Interference from color words in modified Stroop tasks clearly indicates processing of the color words, but from this it does not follow that reduced or absent interference is indicative of reduced or absent processing of the color word. Abundant experimental evidence, obtained with various interference paradigms, shows that the interference can be moderated by experimental manipulations for which it is difficult to argue that they change the processing of a distractor (Baylis & Driver, 1992; Driver & Baylis, 1989;

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La Heij, Helaha & Van den Hof, 1993; La Heij, Kaptein, Kalff, & De Lange, 1995; La Heij, Van der Heijden, & Plooi, 2001; Neumann, 1986; Van der Heijden, Hagenaar, & Bloem, 1984). In the experiments of Van der Heijden et al., for instance, Stroop interference from a distant color word was only obtained when the experiment did not contain integral Stroop stimuli (i.e., the word "BLUE" in red ink). It is difficult to argue that a distant color word is processed shallower when presented in blocks with integral Stroop stimuli. Instead, this effect was probably due to a different response deadline: In blocks with integral Stroop stimuli, reactions were slower, which made it impossible to obtain the Stroop interference from a distant color word (see Phaf, Van der Heijden, & Hudson, 1990). In a similar vein, we will argue in this work that the reduced Stroop interference in the Stroop-dilution paradigm is not due to a reduced processing of the color-word distractor.

Stroop dilution

The Stroop-dilution effect was first reported by Kahneman and Chajczyk (1983). In their experiments, participants had to name the color of a color bar that was accompanied by one or two words. In the one-word conditions, the word was either a congruent color name, an incongruent color name, or a neutral, non-color word. As expected, the color-naming latencies were much longer when an incongruent word accompanied the color bar and shorter when a congruent word accompanied the color bar as compared to the neutral-word condition. In the two-word conditions, the second word was always color-neutral. Adding a second word (henceforth called 'diluter') increased reaction times in the congruent and neutral conditions but caused a decrease of the reaction times in the incongruent condition. That is, the *color word impact* (CWI), defined by Kahneman and Chajczyk as the difference in mean reaction times between the incongruent and congruent condition, decreased. Stroop dilution is then quantified as a reduction of this CWI caused by the simultaneous presentation of a color-neutral word alongside the color-word distractor.

In their experiments, Kahneman and Chajczyk (1983) showed some generality of Stroop dilution: It was also obtained when the congruent condition was omitted– the CWI is then defined as the difference between incongruent and neutral conditions– when the distance between word and color bar was varied, and with a nonword stimulus (a row of Xs) and a wide variety of neutral words as diluters. Across the different experiments, the presence of a second word or another stimulus reduced the CWI by approximately 50%.

Accounting for Stroop dilution with limited capacity

One way to explain the reduced Stroop interference is to assume that the distracting color word is processed less efficiently if a second word-like stimulus accompanies the color word. Two quite different accounts have been based on this assumption. In a limited capacity-attention capture account, Kahneman and Chajczyk (1983) assumed that the two word-like stimuli compete for the limited capacity of the word-recognition resource. Figure 1A gives a schematic representation of this account. Because both stimuli cannot be processed simultaneously, one stimulus captures attention on a given trial. The stimulus that captures attention is processed preferentially and can influence the color-naming process, while the other stimulus is not processed up to the level of word recognition before the color-naming response is initiated. From this view, a 50% decrease of the CWI is precisely what has to be expected, because only on 50% of the trials, can the color word influence the color-naming response. It is important to note that the competition for attention capture occurs only between the two word-like stimuli that compete for the word-recognition resource. According to Kahneman and Chajczyk, attention can be successfully divided between the color bar and the word-like stimuli, because the color bar does not compete for the word-recognition resources.

Brown et al. (1995) gave a quite different account of the Stroop-dilution phenomenon in terms of limited capacity (see Figure 1B). They proposed an "early-visual-interference account" of Stroop dilution. In contrast to Kahneman and Chajczyk's serial-processing capture account, Brown et al. suggested that there is

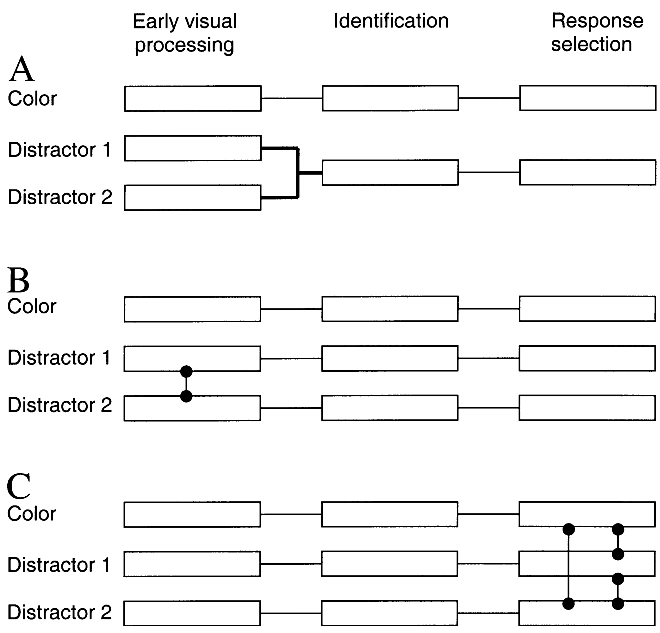

Fig. 1 Schematic representations of the three accounts of Stroop dilution. A – Limited capacity word recognition (Kahneman & Chajczyk, 1983), B – Early visual interference (Brown et al., 1995), C – Unlimited capacity, selection-for-action (van der Heijden, 1992). Note that the figure depicts the assumed loci of Stroop dilution while neglecting Stroop interference. The accounts do not, however, make different assumptions about the nature of Stroop interference. For further explanation see text

parallel processing of the color word and the color-neutral word. Because of limited capacity at an early-visual stage, however, the assembling process from features to words is distorted when more than one word-like object is presented simultaneously. As a consequence of this early-visual interference, color words are "recognized" less accurately, which in turn reduces Stroop interference.

Accounting for Stroop dilution without word-processing dilution

As we stated in the Introduction, it is not a logical necessity that the reduced interference in Stroop dilution is caused by a weakened processing of the color word. Van der Heijden (1992, p. 264–268) proposed another capture account of Stroop dilution based on his unlimited capacity, early selection model of attention (see Figure 1C). In this model selection is argued to be early, because only at an early processing level a distinction between the color bar (the target) and the color word (the distractor) can be made. However, selection does not prevent the parallel processing of the color, distractor word and other stimuli in the visual field up to a semantic level (the unlimited capacity assumption). In this model the function of attention is not to protect limited resources from an information overload. Instead, attention is necessary for the initiation of a response, given an identified stimulus (the "selection-for-action" view, see, e.g., Allport, 1987, 1989; Neumann, 1987; Van der Heijden, 1992).

Central to this account of Stroop dilution is the assumption that the observed CWI consists of two components. The first component results from the attention-independent (unlimited capacity) processing of the color word up to a semantic level. In the incongruent condition an incorrect color word becomes activated, which delays the selection of the correct color name for output. The Stroop effect caused by this first component is dependent only on the readability of the color word (influenced by, e.g., retinal acuity). A second component of Stroop interference is added when the incongruent color word inadvertently captures attention. If that occurs, the activation of the incorrect response does not dissipate until attention is redirected to the color (Van der Heijden, 1992, pp. 220–226). This further prolongs the time needed to select the correct response word.

Van der Heijden assumed that all visual transients (e.g., sudden onsets) lead to attention capture processes, and that multiple visual transients compete for attention capture (see, e.g., Jonides, 1981; Müller & Rabitt, 1989; Yantis & Jonides, 1984, 1990; O'Reagan, Rensink, & Clark, 1999). So, when a color, a color word and a diluter are presented, these three stimuli compete for attention capture (see Figure 1C). Now three possibilities arise. First, if the color bar captures attention, there is a Stroop effect caused by the processing of the color word (the first component discussed above). Second, if the diluter captures attention, attention has to be redirected to the position of the color bar via a 'selection-by-color' procedure (see Van der Heijden, 1992, 1993). The size of the Stroop interference effect in this situation will be mainly determined by the activation of the incongruent color word, just as in the first case. Third, if the color word captures attention, the Stroop effect will be larger because, as discussed above, attentional capture will prevent this strongly activated word from decaying until attention is redirected to the color. Stroop dilution follows from the distribution of these three cases. In displays with only the color word and the color bar, only these two stimuli compete for attention capture. If another word-like stimulus is added, three stimuli compete for attention-capture, and attention capture by the color word is less likely. Therefore, the overall CWI will be reduced by a diluter.

The experiments of Brown et al. (1995)

Brown et al. (1995) presented three lines of evidence that favored an early-visual interference account above an attention-capture account of Stroop dilution (their arguments against Kahneman and Chajczyk, 1983, also apply to Van der Heijden's 1992 account). First, In their Experiment 2 they showed that nonword stimuli and color-neutral words were equally effective as diluters, but that nonword stimuli – when used as a single distractor alongside a color bar – induced less interference then color-neutral words. This finding, the authors argued, provided evidence against the capture account, because "... if a nonword stimulus produces dilution by capturing attention away from a color name that would otherwise have been processed, then nonword stimuli that produce dilution should also capture attention from the color naming process ..." (pp. 1400–1401).

However, this argument rests on the assumption that the interference in color naming caused by a non-color-word distractor is caused only by capturing attention from the color bar. As discussed above, in Van der Heijden's (1992) account, Stroop interference is the sum of two components: (a) interference due to the processing of the distractor and (b) interference due to the (erroneous) attentional selection of the distractor instead of the target. It is very likely that component (a) is larger for non-color words then for nonwords, because words will activate semantic/phonological representations stronger than nonwords. Brown et al.'s (1995) argument is only conclusive if a dissociation of dilution and interference in color naming would hold *within* nonword stimuli. The data set of Brown et al., however, does not allow for such an analysis.

As a second line of evidence, Brown et al. (1995) tested a prediction of the early-visual-interference account. If visual complexity causes Stroop dilution, the more visually complex a stimulus is, the better its ability to produce Stroop dilution should be. In their third experiment, the CWI was more strongly reduced with letter strings, pseudowords, color-neutral words, and character strings (e.g., "&%$?@") as diluters than with repetitive stimuli like a row of Xs or a row of dashes as diluters. With the reasonable auxiliary assumption that repetitive stimuli are visually less complex than non-repetitive stimuli, this confirms the initial prediction. Detailed examination of this experiment, however, reveals some puzzling aspects. Letter strings caused a CWI reduction of 48% (60 ms), which was much more than dilution with pseudowords, color-neutral words or character strings (35% or 43 ms). Although the difference in dilution between letter strings and pseudowords was not significant, it seems too large to accept the null-hypothesis. In our view, this finding, if corroborated by new experimental results, poses serious problems for the early-visual interference account because letter strings are not obviously more visually complex than words or pseudowords.

As a third and final line of evidence, Brown et al. (1995) tested whether Stroop dilution can be eliminated when measures are taken to ensure that the incongruent color word always captures attention. According to attention-capture accounts, Stroop dilution should vanish if attention capture by the diluter is prevented. To that end, the authors manipulated which stimulus appeared at the fixation point in their fourth experiment. They assumed that the element at the point of fixation always captures attention if the inter-stimulus interval (ISI; the time between the offset of the fixation point and the onset of the stimulus element) is as short as 50 ms. With such a procedure and the assumptions made, both capture accounts (Kahneman & Chajczyk, 1983, Van der Heijden, 1992) predict no effect of the presence of a diluter when color words appear at the fixation point and color bars above or below the fixation point. The results, however, showed that even when color words appeared at the fixation point a significant Stroop-dilution effect was obtained. The authors concluded that this finding refutes any capture account of Stroop dilution.

The interpretation of this experiment hinges on the assumption that the fixation point was always attended to. This is, again, questionable. The fixation point was presented for about one second. With such a long cue-target interval, an exogenous cue produces costs rather then benefits, a phenomenon called 'inhibition of return' (Posner & Cohen, 1984). Furthermore, the color bar appeared only in 42% of the trials at the location of the fixation point. Because the participants had enough time (1 s) and a good reason (cue validity of 42%) to withdraw their attention from the fixation point, it is conceivable that attention was not allocated at the point of fixation when the imperative stimulus display appeared. In addition, the interpretation of this experiment is clouded further by the fact that the manipulation of "stimulus at fixation" was confounded with retinal acuity. That is, uncued color words were projected on more peripheral areas of the retina than cued color words.

The present experiments

Given our analysis of the empirical evidence, three issues need further examination. First, the possibility that visual stimuli of equal visual complexity induce different amounts of dilution (as in Brown et al.'s Experiment 3) needs to be scrutinized. Second, it has to be tested whether there is either some form of co-dependency or a dissociation of the dilution effect and the interference-in-color-naming effect when different kinds of nonword stimuli are used. Using nonword stimuli, interference in color naming most likely only reflects attention-capture processes (see Kahneman et al., 1983). Because the same processes are conceived to cause Stroop dilution, at least a monotonic relationship between these two measures has to be expected. Note that these two issues boil down to the question whether visual complexity or attention-capture capability 'makes' a good Stroop diluter.

These first two issues will be examined in Experiment 1, in which the color bar is presented at the point of fixation. We investigated whether the differences in dilution between complex visual stimuli as letter strings and pseudowords are reliable and whether such differences in 'dilution capability' co-vary with 'attention-capture capability' as measured by interference in color naming. If we find a dissociation between these two effects, this would be– in agreement with the arguments put forth by Brown et al. (1995)– strong evidence against an attention-capture account. If, however, letter strings produce more dilution than pseudowords, the early-visual-interference account could only be saved by the ad-hoc assumption that letter strings with vowels (i.e., pseudowords) are visually more complex than letter strings without vowels (i.e., unpronounceable letter strings).

The third issue to be examined is whether the dilution effect disappears when experimental manipulations prevent attention capture by either the color word or the diluter. To that end, in the circular display employed in Experiment 2 (see Figure 2), a pre-cue was used that either indicated the position of the color bar (valid cue)

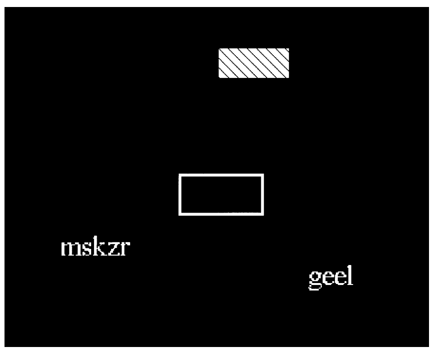

Fig. 2 An experimental display as used in Experiment 2. Note: The figure shows an example of a neutral cue condition. The striped bar represents a color bar. The cue is depicted in the Figure, although it was removed at target onset. In the subjective experience, however, the cue was still visible at target onset

or a “neutral” position (the central position in the display; neutral cue). The rationale was that, according to the capture account as proposed by Van der Heijden (1992, pp. 264–268), the presentation of a pre-cue at a position different from the position of the diluter itself will eliminate the attention capture by the distractors and, for that reason, the Stroop-dilution effect.

This experiment also allows distinguishing the predictions of the two capture accounts. The limited capacity-capture account of Kahneman and Chajczyk (1983) predicts that presentation of a cue will have no effect on Stroop dilution because – according to that account – only the two word-like stimuli compete for attention capture. Cueing the position of the color bar or the central position leaves intact the *raison d'être* for attention capture: the limited capacity for word-recognition.

To anticipate the results of our experiments: Experiment 1 shows that (a) diluters that are similar in visual complexity do induce different dilution effects (confirming a similar trend in the Brown et al., 1995, data), and (b) across the various diluters used, the size of the dilution effect co-varies with the size of the interference in color-naming. Experiment 2 reveals that the use of a pre-cue eliminates Stroop dilution. Finally, Experiment 3 shows that Stroop dilution can be obtained with the materials and procedure used in Experiment 2. In combination, our results corroborate the attention-capture account proposed by Van der Heijden (1992).

Experiment 1

The main objective of this experiment was to evaluate whether different kinds of nonword diluters differ in their capability to induce Stroop dilution and whether such differences co-vary with ‘attention-capture capability.’ This capability was measured by the interference in color naming that a diluter produces when presented as a single distractor alongside the to-be-named color bar. Brown et al. (1995) found a dissociation between the amount of Stroop dilution caused by a stimulus and the amount of Stroop interference that it caused when used as a single distractor. If we would replicate this result with nonword stimuli, this would provide strong evidence against an attention-capture account of Stroop dilution. In addition, the account of Brown et al. predicts that the stimuli comparable in visual complexity should cause comparable amounts of Stroop dilution. To test this prediction, we used the same type of diluters as Brown et al., which were judged by them to be of a comparable degree of visual complexity. These were color-neutral words, pseudowords, unpronounceable letter strings, and character strings.

Method

Participants Ten students and one non-scientific staff member from the University of Leiden, aged 19–42, participated in the experiment. All participants had normal or corrected-to-normal vision. Participants were run individually and paid for their participation.

Material and displays Four color bars in red, green, blue, and yellow were created. The color bars were matched in brightness with the help of the drawing-program “Paint Shop Pro” to prevent gross brightness differences between the different colors. The bars extended 64×31 pixels equaling 2.00° by 0.99° of visual angle on a 17-inch monitor at a viewing distance of 60 cm. The colors were close to saturation; complete saturation was not possible without violating the brightness constraints.

The Stroop-word and the Dilution stimuli were constructed in “Times New Roman” font with letter size 16. All letters were presented in lowercase. These stimuli were drawn in white and embedded in a black frame of 64×31 pixels. (This frame was not visible against the black background.) The largest letter/character string was at most 8 pixels (0.24° of visual angle) smaller than the color stimuli in both the horizontal and the vertical dimension.

All (Dutch) color words were monosyllabic (“blauw” [blue], “geel” [yellow], “groen” [green], and “rood” [red]). The words used as distractors in the “color-neutral-word” level of the Stroop-word factor were matched with the color words with respect to word-familiarity (de Vries, 1986) and length. The neutral words used as diluters were matched with the color words in length only; perfect matching of familiarity was not possible due to the further constraints imposed on the neutral words. These constraints were: same grammatical category, not associated with any concept of color or warmth, and not sharing an initial letter with one of the color words (these variables have been shown to affect color-naming latencies; see MacLeod, 1991).

Pseudowords were created by using the syllable onsets and codas from the color-neutral words and combining them in an orthographically legal way with a Dutch nucleus. So, also the pseudowords did not share an initial letter with any of the color words. Pseudowords were further matched with the color words in length (and thus also with the neutral words) and cross-checked for their true non-existence with an official Dutch word list (Nederlandse Taalunie, 1995).

Letter strings were generated by combining the consonants from the neutral words so that no two consonants following each other could be reasonably pronounced within syllable boundaries. Letter strings were also matched in length with the color words (and thus also with the other stimuli). Character strings were created by using the non-orthographic signs of a standard computer keyboard (i.e., !’@#$%ˆ&*(){}[]“|\?/) and matched in length with the other stimuli. A complete list of Stroop words and diluters is given in the Appendix.

These stimuli were used to create an experimental display as follows. Color bars were always shown at fixation. The center of the Stroop words and the dilution stimuli appeared 1.30° of visual angle above and/or below the center of the color bar. The nearest edge of a distractor had a distance to the color bar of about 0.40° of visual angle. All distractors appeared above and below the color bar in equal frequencies.

Apparatus and procedure The experiment was run on a 486/66 MHz DOS-PC. The computer program that controlled stimulus presentation was written with the help of the PEST1.9 (Duwe & Claußen, 1995). Reaction times were recorded with a voicekey attached to the parallel port of the computer. After each color-naming response, the accuracy was recorded by the experimenter via the keyboard.

Each participant was given an on-line instruction with examples of experimental displays. In the instruction, participants were asked to name the color of the color bar as quickly and accurately as possible. After reading the instructions, participants completed 19 practice trials (one of each condition). Then, the actual experiment started. Randomization was done with some constraints to prevent serial effects such as the “distractor-suppression effect” (Neill, 1977; also known as negative priming, see Tipper, 1985). The randomization procedure further prevented any color from being named twice in succession, and ensured that each color was repeated within a series of about 10 trials.

Each trial began with three Xs appearing at the center of the screen, where the color bar would appear. After 300 ms, this fixation-point disappeared and the experimental display appeared (the computer needed 19 ms to switch off the screen, blank the screen, and load the experimental display). The imperative display was shown for 200 ms. The reaction time and accuracy were recorded and, after a variable break of approximately a second for saving the data and preparing the next trial, the following trial began. No feedback about accuracy was given. Feedback about the number of trials already presented was given at every hundredth trial.

Using four colors, twelve incongruent color-color word combinations are possible. Therefore, twelve displays were created for each of the 19 conditions. Each display was shown twice, which yielded a total of 19×12×2 = 456 trials per participant.

Design The experiment entailed two factors. The first factor was the type of Stroop word. This factor had four levels: incongruent color words, color-neutral words, congruent color words, and no Stroop word (color-alone). The neutral-word condition was added in order to allow comparisons of congruence and interference effects. The second factor was the type of the diluting stimulus. There were four different dilution stimuli: letter strings (e.g., "ptmw"), characters (e.g., "{&]*"), pseudowords (e.g. "joes"), and color-neutral words (e.g., "slim"[smart]). This resulted in a 4×4 design. In addition, three conditions without a diluter were added to serve as baselines. These were a color-bar-only condition, a color-bar-plus-incongruent-word condition, and a color-bar-plus-congruent-word condition. (The control condition with only a color bar and a neutral word arises from crossing the color-bar alone condition of the Stroop factor with the neutral-word condition of the Dilution factor.)

Results

The following data-trimming procedure was used: reaction times (RTs) smaller than 350 ms, RTs larger than 1500 ms– accounting for 1.4% of the trials– and RTs of incorrect responses were discarded. The remaining RTs were used in the calculations of the means. Table 1 shows the mean RTs and error percentages obtained in the various experimental conditions. The average error percentage was only 2.1% (about nine errors per participant dispersed over 19 conditions). We considered this percentage too low to allow a meaningful analysis. Given a 0.82 rank-order correlation between error rates and color-naming latencies across conditions there was no evidence whatsoever for a speed-accuracy trade-off between conditions.

Dilution effects

Dilution effects were estimated by calculating the CWI (congruent – incongruent Stoop condition) and comparing these values for all five Dilution conditions. Note that a lower CWI is equivalent to a stronger Stroop-dilution effect. A repeated-measure analysis of variance (ANOVA) on the CWIs revealed a significant main effect ($F(4, 40) = 7.72$, $p < 0.001$, $MSE = 1617$). A Newman-Keuls post-hoc procedure ($p < 0.05$) revealed that the CWI obtained in all with-diluter conditions was smaller than the CWI without a diluter (143 ms). That is, all diluters caused significant dilution. In addition, the CWI with letter strings (56 ms) was significantly smaller– thus more strongly diluted– than the CWI obtained with character strings (107 ms).

Interference in color naming

To test whether the diluters produced significant interference in color naming when used as single distractors, a separate ANOVA was performed on the color-naming latencies of the no Stroop-word condition with diluter-type as factor. This analysis revealed a significant effect of diluter type, $F(4, 40) = 5.29$, $p < 0.01$, $MSE = 585$, indicating that the presence of a diluter induced interference in color naming. In order to examine the strength of the interference in color naming, a Newman-Keuls post-hoc procedure was used ($p < 0.05$). The procedure revealed that color naming was slowed significantly in comparison to the color-bar only condition by letter strings (34 ms) and neutral words (30 ms). In addition, color-naming was slower with letter strings or neutral words as distractors than with character strings as distractors (only 7 ms slower than

Table 1 RTs in ms and error percentages in the various conditions of Experiment 1

Stroop-word Condition	Dilution condition									
	Letter strings		Characters		Pseudowords		Words		No diluter	
	rt	%e	rt	%e	rt	%e	rt	%e	rt	%e
Incongruent	649	3.21	689	5.71	659	4.72	661	5.86	703	6.75
Color-neutral	625	2.29	633	0.74	631	0.74	642	1.74	–	
None	635	1.88	604	0.59	619	0.92	633	2.06	597	0
Congruent	591	1.55	582	0.18	581	0.92	575	0.41	559	0.74
CWI	58		107		78		86		144	
Dilution	59.7%		25.7%		45.8%		40.3%			
Interference	38		7		22		36			

CWI is defined as the difference between the congruent and incongruent Stroop-word condition. Dilution is defined as the proportion of CWI reduction in relation to the no-diluter condition. Interference refers to the interference in color naming produced by the different diluters and is derived by subtracting the color-naming latency of the color-bar-alone condition (597 ms) from the respective values in the color-bar-plus-diluter conditions the color-bar only condition). All other comparisons failed to reach significance.

A comparison of the dilution effects and the interference-in-color-naming effects shows that the two effects are proportional within the nonword diluters. In both analyses, the letter strings cause the strongest effects and the character strings cause the weakest effects, while pseudowords produce intermediate values. To test the correspondence statistically, we calculated the correlation between Dilution and interference-in-color naming measures. This correlation was close to perfect ($r = 0.992$, $t(1) = 8.0$, $p < 0.05$).

Discussion

The data of the present experiment replicate the main findings of Brown et al. (1995, Experiment 3). Character strings, letter strings, pseudowords, and neutral words produced a substantial dilution effect, and the average size of this effect (43% dilution) was rather similar to the one reported by Brown et al. (38% dilution). However, two additional results were obtained. First, although all diluters were similar in visual complexity, they differed significantly in the amount of dilution they induced: character strings induced the least amount of dilution (37 ms), and letter strings the largest amount of dilution (86 ms), confirming a similar trend in Brown et al.

The question could be raised, however, whether the different type of stimuli were indeed of similar visual complexity. Following Brown et al. (1995), we defined visual complexity as the number of complex segments (letters or characters) a stimulus contains. It remains possible, however, that one class of stimuli is composed of more complex segments the other classes of stimuli. To address this issue, we estimated visual complexity using the stroke-number measure (Coney, 1998). The stroke measure is well suited for the present purposes, because Brown et al. assume that early-visual interference occurs at a stage where features are combined to form letters. Simple visual features probably compare to strokes during writing. Therefore, two independent observers blind to the purpose of the experiment judged how many strokes they needed to copy the stimuli (inter-rater correlation = 0.713, $p < 0.01$). According to these measures, character strings were the most complex stimuli (9.75 strokes), letter strings less complex (8.75 strokes), and pseudowords the least complex (8 strokes). According to this measure, differences in visual complexity cannot explain the difference in ‘dilution capability’ between these nonword stimuli. If this was the case, character strings should be the most efficient diluters; they are, however, the least efficient diluters. These differences– difficult to explain in terms of visual complexity– can be explained by ‘attention-capture capability.’

Our second additional result was that the Stroop dilution effects induced by the various nonword diluters were proportional to their interference effects in color naming. The character strings, which produced the smallest dilution effects, also produced almost no interference in color naming. The letter strings, which produced the strongest dilution effects, also produced the strongest interference in color naming. This result is in line with a capture account, which assumes that (a) dilution is based on attention capture, and (b) that the same attention capture process is also at the basis of interference in color naming.

It should be noted, however, that the results of Experiment 1 favor a capture account only in a rather indirect way. For instance, the attention-capture account does not predict that letter strings should capture attention more strongly than pseudowords. However, the attention-capture account does predict that if letter strings produce more interference in color naming (‘attention-capture capability’), they should also produce more Stroop dilution (‘dilution capability’) and that was what we observed.

The present results do not allow deciding between the capture accounts of Kahneman and Chajczyk (1983) and Van der Heijden (1992). More direct evidence, based on a manipulation of attention capture is needed. This was the purpose of Experiment 2.

Experiment 2

In this experiment, we tested whether Stroop dilution can be eliminated when measures are taken to prevent the distractors or diluters from capturing attention. A similar experiment was devised by Brown et al. (1995, Experiment 4) in which– in one of the conditions– the color bar was presented at the point of fixation. As argued in the Introduction, that experiment suffered from several drawbacks: a relatively long cue-target interval combined with low cue validity and the confounding of the cueing procedure with retinal acuity.

In the present experiment, we attempted to avoid these problems. All stimuli were positioned on an imaginary circle to prevent differences in retinal acuity. Differences in retinal acuity could, however, still arise due to eye movements. To prevent useful eye movements, the total time from the onset of the cue until the offset of the imperative display was set below 200 ms. In order to guarantee a proper allocation of attention within this small exposure duration, attention capture was manipulated by means of a location cue. This location cue was either valid or neutral. This allows evaluation of the effectiveness of the cueing procedure without using an invalid cue. When invalid cues are used, participants may attempt (and sometimes succeed in) withdrawing attention from the cue (see Van der Heijden, 1992).

The predictions of the Brown et al.’s (1995) early-visual-interference account are straightforward. Regardless of cueing, Stroop dilution should be obtained, because cueing the position of the color bar does not eliminate early-visual interference arising from the parallel processing of the color word and the diluter.

In a similar vein, the capture account of Kahneman and Chajczyk (1983) predicts Stroop dilution despite cueing. According to this latter view, competition for attention capture between the two distractors arises, because they cannot be processed in parallel. The necessity for attentional selection of one of the distractors for further processing by limited resources is left unchanged by cueing the position of the color bar.

The capture account as proposed by Van der Heijden (1992, pp. 264–268) predicts that no Stroop dilution will be obtained when a cue is used. When the cue is presented its sudden onset captures attention. If the cue is valid, the color bar will immediately be selected and no dilution will be observed. The prediction of Van der Heijden's account for the neutral-cue condition is somewhat more complex. As discussed above, Van der Heijden assumed that when a display element other than the color bar captures attention, attentional selection is redirected to the color by means of a "selection-by- color" procedure (see Phaf et al., 1990, and Van der Heijden, 1992, p. 268, for details). Indeed, Theeuwes (1991) showed that once attention is captured – as in the present case by the neutral cue – sudden onsets appearing within 500 ms do not capture attention. Thus, Van der Heijden's attentional-capture account makes the somewhat counterintuitive prediction that neither in the valid-cue condition, nor in the neutral-cue condition, should Stroop dilution be observed: In both cases the cue prevents the diluter from capturing attention. Of course, according to Van der Heijden's account, the parallel processing of the incongruent color word should still induce Stroop interference (the first component of Stroop interference, discussed above).

Method

Participants Twenty students from the University of Leiden participated in the experiment. The mean age was 21.0 with a range from 18 to 26. All participants had normal or corrected-to-normal vision. Participants were run individually and paid for their participation.

Materials and displays In a first run of the experiment, it became evident that some participants could not discriminate reliably between the colors yellow and green, probably because of the short exposure duration used (119 ms compared to a 200 ms exposure in Experiment 1). Therefore, the color yellow was replaced by the color violet.

The color bars subtended 53×22 pixels on a 17inch screen, corresponding to a visual angle of $1.60^{o} \times 0.66^{o}$ at a viewing distance of 60 centimeters. Hues were matched in brightness with the help of the computer program Paint Shop Pro to prevent gross brightness differences between the different colors. The Stroop-word and Dilution stimuli were drawn in "Times New Roman" font with a letter size of 16 pixels. These stimuli extended about 1.5^{o} of visual angle in width and 0.5^{o} of visual angle in height. All (Dutch) color words used were monosyllabic ("rood" [red], "groen" [green], "blauw" [blue], and "paars" [violet]). The neutral words used in the Stroop-word conditions were the same as in Experiment 1.

As diluters, the same letter strings were used as in Experiment 1 with one exception. The first two letters of the letter string "ptmw" were exchanged in position, because this letter string started with a "p", as does the Dutch color word for violet ("paars").

With these stimuli, displays were created by positioning the stimuli on an imaginary circle that was positioned at the center of the screen. The imaginary circle had a radius of 3.0^{o} of visual angle, leading to a radius-stimulus size ratio of two; a ratio that led to reliable Stroop interference in the experiments of Hagenaar and Van der Heijden (1986).

The centers of the stimuli were positioned on the circle so that the stimuli would form a virtual equilateral triangle. The stimuli were prevented from being aligned in the horizontal or vertical axis (Driver & Baylis, 1992, obtained more interference when stimuli were aligned). This was achieved by turning the virtual triangle with the anchor points for the stimuli either 7.5^{o} to the left or to the right from an upright position (see Figure 2).

Every stimulus appeared in all six possible positions with the same frequency. Furthermore, positions of color bars, Stroop words, and diluters were balanced in every cell of the experimental design.

The location cue was an outline rectangle with a line width of two pixels, which subtended an area slightly larger than the color bar (63×32 pixels, corresponding to $1.9° \times 1.0°$ of visual angle). The neutral location cue was presented in the center of the screen, and the valid location cue virtually "surrounded" the color bar. (The cue was removed physically at the onset of the color bar, but seemed to surround the color bar in subjective experience.)

Apparatus and procedure The apparatus was the same as in the first experiment. The computer program that controlled stimulus presentation was written with the help of the PEST1.9 (Duwe & Claußen, 1995). Participants received instructions and practice trials as in Experiment 1, then, the actual experiment started.

At the beginning of each trial, a fixation cross was displayed at the center of the screen for 200 ms. The participants were instructed to attend the fixation cross. After a blank interval of approximately 20 ms, the location cue appeared for 51 ms (i.e., three display-refresh times), immediately followed by the experimental display with the to-be-named color bar. The display was visible for 119 ms (i.e., seven display-refresh times), leading to a combined duration of cue and stimulus of 170 ms, which is too short to allow useful eye movements. Then, the reaction time and accuracy were recorded and, after a variable interval of approximately one second, the next trial began. No feedback about accuracy was given. Feedback about the number of trials already presented was given at every hundredth trial.

Using four target colors, there are twelve possible incongruent color word-color combinations. Each of these twelve combinations was used two times, yielding 24 measurements per condition. With 16 conditions, this resulted in a total of 384 trials per participant. The displays were shown in a pseudo-randomized order (see Experiment 1).

Design The experiment entailed three factors. The first factor was the type of Stroop word. This factor had four levels: incongruent color words, color-neutral words, congruent color words, and no distractor word (color-alone). The second factor was the dilution factor with two levels: presence or absence of a diluter (a letter string). The third factor was the cue factor, with two levels: "valid cue" and "neutral cue." This resulted in a 4×2×2 design.

Results

The data were treated in the same way as in Experiment 1. The trimming procedure lead to a rejection of 0.9% of the trials. Table 2 shows the mean RTs and error percentages in the various experimental conditions. The average error percentage was 1.9% (on average seven errors per participant), which was considered too low to allow a meaningful analysis. Given a 0.48 rank-order correlation between error rates and color-naming latencies across conditions there was no evidence whatsoever for a speed-accuracy trade-off.

Table 2 RTs in ms and error percentages in the various conditions of Experiment 2

Diluter	Cue	Stroop-Word Condition								
		Incongruent		Neutral		None		Congruent		CWI
		rt	%e	rt	%e	rt	%e	rt	%e	
Absent	Neutral	650	3.5	634	2.1	615	2.5	602	1.3	48
Absent	Valid	636	4.0	624	2.3	612	0.8	586	1.7	50
Present	Neutral	661	2.5	632	1.3	622	2.5	617	0.6	44
Present	Valid	647	1.3	629	1.3	624	1.9	606	0.6	41
Mean		649	2.8	630	1.7	618	1.9	603	0.9	46

A 4×2 × 2 ANOVA was performed on the data with type of Stroop-word (incongruent, neutral, no Stroop word, and congruent), the diluter factor (present or absent) and cue validity (valid or neutral) as within-subject factors. In this analysis, all main effects appeared significant: the Stroop-word factor, $F(3, 57)=54.02$, $p<0.001$, $MSE = 560$, (an overall CWI of 46 ms); the dilution factor, $F(1, 19)= 21.08$, $p<0.001$, $MSE = 374$, (reaction times were on average 10 ms larger when a diluter was present), and the cue-validity factor, $F(1, 19) = 20.79$, $p<0.001$, $MSE = 321$, (a 9 ms facilitation in case of a valid cue).

None of the interactions approached significance (Stroop-word factor by dilution factor: $F(3, 57) = 1.00$, $p = 0.399$, $MSE = 771$; Stroop-word factor by cue-validity factor: $F(3, 57) = 1.78$, $p = 0.161$, $MSE = 513$; dilution factor by cue-validity factor: $F(1, 19) = 0.69$, $p = 0.417$, $MSE = 505$; Stroop-word factor by dilution factor by cue-validity factor: $F(3, 57) = 0.17$, $p = 0.917$, $MSE = 318$). That is, neither cue position nor adding a diluter affected the size of the CWI.

Discussion

The present experiment was successful in producing a reliable Stroop interference effect that was of the same magnitude as observed by Hagenaar and Van der Heijden (1986), who used a similar display configuration. However, no evidence whatsoever for Stroop dilution was obtained. This result is difficult to reconcile with the assumption of limited capacity. The observation of a significant Stroop effect proves that color words were processed up to the level of word recognition. Because color words and diluters appeared at identical positions over different trials, it follows that diluters were also processed alongside the color words. Despite this parallel processing, the Stroop effect was not moderated by the presence of a diluter. Therefore, the present results strongly challenge the capture account of Kahneman and Chajczyk (1983) and the early-visual-interference account of Brown et al. (1995). According to these accounts the color word and the diluter cannot be processed in parallel without, at least, mutual interference.

In contrast, the capture account proposed by Van der Heijden (1992) is supported by the results. As predicted, no dilution effect was observed when attention capture is manipulated by a cue, valid or neutral, that prevents attention capture by one of the distractors. However, it could of course be argued that the lack of a dilution effect is not due to the use of a precue, but to the specific display configuration used. For that reason, Experiment 3 examined whether Stroop dilution can be obtained with the kind of display configuration used in the present experiment.

Experiment 3

In this experiment, we investigated whether Stroop dilution can be obtained with the display configurations used in Experiment 2. The same displays as in Experiment 2 were used. The only difference between the two experiments was that in Experiment 3 no cue was presented. This was achieved by a simple adjustment of the program used in Experiment 2: the color of the cue was changed into the display's background color.

Method

Participants Sixteen students from the University of Leiden participated in the experiment. The mean age was 22.7 with a range from 18 to 29. All participants had normal or corrected-to-normal vision. Participants were run individually and paid for their participation.

Materials, apparatus, and procedure Material, apparatus, and procedure were identical to the previous experiment.

Design The experimental design was similar to the one in Experiment 2, with the exception that the cue factor (valid versus neutral) was omitted. This resulted in a four-by-two design with a four-level Stroop factor (incongruent-word, neutral-word, no Stroop word, and congruent-word) and a two-level Dilution factor (diluter-present and diluter-absent). In each of the resulting eight conditions, 48 measurements per participant were taken, resulting in a total of 384 trials per participant.

Results

The data were treated in the same way as in Experiment 1. Data trimming lead to the rejection of 1.3% of the trials. Table 3 shows the mean RTs and error percent-

Table 3 Mean RTs in ms and error percentages in the various conditions of Experiment 3

Diluter	Stroop-Word Condition								
	Incongruent		Neutral		None		Congruent		CWI
	rt	%e	rt	%e	rt	%e	rt	%e	
Absent	681	1.9	643	2.2	639	1.6	611	1.0	70
Present	672	2.2	651	1.6	644	1.5	631	1.5	41
Mean	676	2.1	647	1.9	641	1.6	621	1.3	56

ages in the various experimental conditions. The average error percentage was 1.7% (on average less than seven errors per participant), which was considered too low to allow a meaningful analysis. Given the small but positive rank-order correlation between RTs and error rates (0.18), it is unlikely that the reaction time results were affected by a speed-accuracy trade-off between conditions.

An ANOVA performed on these data with the Stroop-word conditions (incongruent, neutral word, color-alone, and congruent) and the diluter conditions (present or absent) as within-subject factors, revealed a significant Stroop effect, $F(3, 45) = 33.54$, $p < 0.001$, $MSE = 510$, but not a significant effect of dilution condition, $F(1, 15) = 1.71$, $p = 0.211$, $MSE = 651$. The interaction between the two factors, however, was significant, $F(3, 45) = 2.91$, $p < 0.05$, $MSE = 353$, which indicates dilution. With a diluter the CWI was 41 ms, without a diluter the CWI was 70 ms.

Discussion

The results of the present experiment clearly show that it is possible to obtain Stroop dilution with the display configuration used in Experiment 2. Apparently, the somewhat larger distance between color word and diluter in comparison to the configuration used in Experiment 1 does not eliminate Stroop dilution. This finding is in accordance with Kahneman and Chajczyk (1983), who reported that color word-diluter distance is not an important variable in Stroop dilution. We conclude that the lack of Stroop dilution in Experiment 2 was not due to the display configuration used. Instead, it was the presence of a precue that was responsible for the absence of a dilution effect.

General Discussion

The starting point of the present study were three findings, reported by Brown et al. (1995), that seemed to refute any attention-capture account of Stroop dilution. First, these authors reported the absence of a correlation between the amount of dilution and the amount of attention capture induced by a certain distractor (e.g., a word, nonword, letter string, or a character string). Second, the amount of dilution appeared to co-vary with the visual complexity of the diluter. Finally, Stroop dilution was not eliminated when measures were taken to ensure that the color bar always captured attention.

In the Introduction, we question the validity of these results. We reported three experiments that tested some crucial aspects of Brown et al.'s 1995) findings. Our experiments yielded three main findings, which all bear out the critical arguments raised. First, Experiment 1 showed that when nonword diluters are considered, the amount of dilution and the amount of interference in color naming do co-vary (see the Introduction for an explanation of why only nonword diluters should be considered in this comparison). Second, we obtained evidence that dilution does not always co-vary with visual complexity of the diluter– in line with part of the data reported by Brown et al. Whereas letter strings and character strings are rather similar in this respect, they produced different amounts of dilution. Third, the results of Experiments 2 showed that Stroop dilution could be eliminated when a precue is used.

This latter result strongly challenges the assumption that Stroop dilution is caused by limited capacity. If there is limited capacity in word recognition, the simultaneous presentation of two word-like stimuli should lead to a shallower processing of these stimuli in comparison to when only one word-like stimulus is shown. Our finding that Stroop interference caused by a color word did not decrease when a second word-like object is presented simultaneously, suggests that two word-like objects can be processed in parallel without mutual interference. Experiment 3 verified that the absence of a Stroop-dilution effect in Experiment 2 was not due to the specific display configuration used. In this third experiment, the observed Stroop effect with a diluter present was of similar size as the overall Stroop effect in Experiment 2. This is in line with the unlimited-capacity attention-capture account, as it indicates that adding a diluter in Experiment 3 had a similar effect as the cue in Experiment 2. It attracted attention away from the color word, which dilutes the Stroop effect. In Experiment 2, however, adding a diluter did not have any effect on the Stroop effect, because the cue already captured attention away from the color word.

These results favor an explanation of Stroop dilution in terms of the unlimited capacity-early selection model of attention put forward by Van der Heijden (1992). According to this view, attention is not necessary for the processing of stimuli up to a semantic level. Instead, attention plays a role in the selection of an identified stimulus for further processing ("selection-for-action").

In this view, Stroop interference has two components: (1) a delay in the selection of the correct response word due to the activation of an incongruent distractor word (the unlimited capacity aspect of the model) and (2) an additional delay that occurs when, instead of the color patch, an irrelevant display element captures attention. This second component is larger when the selected display element is an (highly activated) incongruent color word than when it is a nonword or a character string. In Van der Heijden's view, the diluter reduces Stroop interference because it reduces the probability that the incongruent color word captures attention.

It is interesting to integrate our findings into the history of Stroop research on visual selective attention. Early results showing Stroop effects with spatially separated color bars and color words (Dyer, 1973; Gatti & Egeth, 1978) were interpreted as indicating unlimited-capacity processing of unattended distractors. Kahneman and Treisman (1984) challenged this interpretation and put forward a classical limited-capacity early-selection model of visual attention on the basis of the following two observations. First, Kahneman and Henik (1981) showed that Stroop interference was much larger when word and color were spatially integrated than when they were spatially separated. In addition, in some conditions, external color words caused no Stroop interference. However, Van der Heijden et al. (1984) showed that the results of Kahnman and Henik can be explained by an unlimited-capacity model of attention and were partly due to the mixture of conditions within blocks (see also the simulation of these results by Phaf et al., 1990).

Kahneman and Treisman's (1984) second argument for a limited-capacity view was the observation of Stroop dilution. Indeed, Stroop dilution is widely cited as a hallmark showing limited capacity (e.g., Pashler, 1997, p. 64). The present experiments, however, indicate that this view is most probably incorrect. Stroop dilution seems not to be due to limited capacity, but rather due to a competition of abrupt onsets for attention-capture. If this competition for early selection does not take place because a pre-cue already captured attention, the Stroop effect is not diluted by additional display elements. Given that attention capture is selection by location, thus 'early selection,' it may be stated that Stroop dilution is not a limited-capacity, but rather an early-selection effect.

Over the last decade, new hybrid theories of selective visual attention have been proposed that might also account for our present findings. According to the models of, for instance, Desimone and Duncan (1995) or Lavie (1995, Lavie & Fox, 2000) selection may be early or late depending on the task and stimulus load. However, these models seem to agree with most early-selection or late-selection theories on one point: If at a certain processing stage a selection is made, this prohibits processing of distractors beyond this stage. Van der Heijden (1987) already noted that theorizing on attention tends to confound selection and capacity issues. In this theorizing, early selection implies limited capacity and unlimited capacity implies late selection. In our view, however, results with the Stroop task force a reconsideration. The results of Kahneman and Henik (1981) and Kahneman and Chajczyk (1983) certainly indicate early selection (see also Hagenaar & Van der Heijden, 1986). However, the results of Van der Heijden et al. (1984) and the present results indicate unlimited-capacity processing despite early selection. Even if a location cue facilitates early selection, Stroop interference can still be observed. Therefore, the present results seem to necessitate hybrid models to incorporate the possibility of a dissociation between selection and processing.

Converging evidence for a dissociation between early attentional selection and unlimited capacity processing has been reported by Martens (2001). In a rapid serial visual presentation (RSVP) task, Martens observed an attentional-blink effect. That is, if participants identified a target, a subsequent target appearing in a time window of a half second after the presentation of the first target was likely to be missed. Therefore, it seems that these 'blinked words' did not receive attention, otherwise they should have been reported. However, in a later word-identification task, blinked items from the RSVP task produced significant semantic priming, which provides evidence that words in an attentional blink are still processed up a stage of word-recognition.

Rensink (2001) has proposed a model of visual attention to account for the effect of "change blindness." According to this author, automatic visual processes, independent of attention, lead to the identification of the 'gist' of a scene. However, attentional selection is necessary when a particular detail has to become available for overt report. Indeed, the finding of change blindness itself can be considered an instance of a dissociation between processing and selection. Given the gross changes in change-blindness displays, it is difficult to argue that these properties (such as color changes) cannot be processed due to limited capacity of the visual system. Nevertheless, attentional selection based on position, thus 'early selection,' is still necessary in order for an overt report of such a change.

Summarizing, our data make it difficult if not impossible to explain Stroop dilution in terms of limited capacity processing. Instead, the results corroborate the attention-capture account of Stroop dilution by Van der Heijden (1992, p. 264–268), according to which attention capture does not lead to privileged processing but rather to privileged access to action generation. In the general context of earlier Stroop research, the present data are in line with Van der Heijden's view that selective visual attention affects processing at an early stage, but that this does not prohibit the processing of distractors. Given that such a divorce between selection and processing seems necessary, the current results cannot easily be accounted for by hybrid models of visual attention as the perceptual load model (Lavie, 1995) or the biased-competition model (Desimone & Duncan, 1995).

Appendix

Diluters and Stroop words

A complete list of diluters and Stroop words is given in the following two tables.

Diluter type						
Letter strings	nrvt	ljdbf	ptmw	tnlg	kgtcs	mzksr
Character strings	{&]*	%{#	)$()!	@”&ˆ	#\?“(	[>%:~
Pseudowords	loors	sleg	dwai	joos	stirs	meing
Neutral words	mooi	jong	slim	dwars	sterk	slank
[Translations]	[beau-tiful]	[young]	[smart]	[trans verse]	[strong]	[slim]

Stroop words				
color words	blauw [blue]	geel [yellow]/ paars[violet]	groen [green]	rood[red]
neutral words	lang [long]	klein [small]	zwaar [heavy]	

References

Allport D.A. (1987). Selection for action: some behavioral and neuropsychological considerations of attention and action. In H. Heuer & A.F. Sanders (Eds.), *Perspectives on Perception and Action* (pp. 395–419). Hillsdale, N.J.: Lawrence Earlbaum.

Allport, D.A. (1989). Visual attention. In M.J. Posner (Ed.), *Foundations of cognitive science* (pp. 631–682). Cambridge, MA: MIT Press.

Baylis, G.C. & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics, 51,* 145–162.

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.

Coney, J. (1998). The effect of complexity upon hemispheric specialization for reading Chinese characters. *Neuropsychologica, 36*, 149–153.

Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18,* 193–222.

Driver, J. & Baylis, G.C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 448–456.

Driver, J. & Tipper, S.P. (1989). On the non-selectivity of selective seeing: Contrasts between interference and priming in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 304–314.

Duwe, I. & Claußen, H (1995). PEST1.9: *Eine Psychologische Experimental-Steuerung für DOS-PC's.* [A Psychological Experimental Control for DOS computers] Universität Bielefeld, SFB 360: Report 95/5 Situierte künstliche Kommunikatoren.

Dyer, F.N. (1973). Interference and facilitation for color naming with separate bilateral presentations of the word and the color. *Journal of Experimental Psychology, 99,* 314–317.

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

Hagenaar, R. & Van der Heijden, A.H.C. (1986). Target-noise separation in visual selective attention. *Acta Psychologica, 62,* 161–176.

Jonides, J. (1981).Voluntary vs. automatic control over the mind's eye's movement. In J.B. Long & A.D. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, N.J.: Earlbaum.

Kahneman, D. & Chajzyk, D. (1983). Tests of the automaticity of reading: Dilution of color-irrelevant stimuli. *Journal of Experimental Psychology : Human Perception and Performance, 9,* 497–508.

Kahneman, D. & Henik, A. (1981): Perceptual organization and attention. In M. Kuboovy & J.R. Pomerantz (Eds.), *Perceptual Organization* (pp. 181–211). Hillsdale, N.J.: Earlbaum.

Kahneman, D. & Treisman, A.M. (1984). Changing views of attention and automaticity. In R. Parasuraman & P.R. Davies (Eds.), *Varieties of Attention* (pp. 29–61). New York: Academic Press.

La Heij, W., Heleha, D., & Van den Hof, E. (1993). Why does blue hamper the naming of red: Color-color interference and the role of locational (un)certainty. *Acta Psychologica, 83,* 159–177.

La Heij, W., Kaptein, N.A., Kalff, A.C., & Lange, L. de (1995). Reducing color-color interference by optimizing selection for action. *Psychological Research, 57,* 119–130.

La Heij, W., van der Heijden, A.H.C., & Plooij, P. (2001). A paradoxical exposure-duration effect in the Stroop task: Temporal segregation between stimulus attributes facilitates selection. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 622–632.

Lavie, N. (1995) Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 451–468.

Lavie, N. & Fox, E. (2000). The role of perceptual load in negative priming. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1038–1052.

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

Martens, S. (2001). *Blinks of the mind: Interference in Memory and Attention.* Ph.D. dissertation. Leiden, the Netherlands: Universiteit Leiden.

Merikle, P.M. & Gorewich, N.J. (1979). Spatial selectivity in vision: Field size depends upon noise size. *The Bulletin of the Psychonomic Society, 14,* 343–346.

Müller, H.J. & Rabbit, P.M.A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 315–330.

Nederlandse Taalunie (1995). *Woordenlijst Nederlande taal* [Dutch vocabulary]. Den Haag: SDU.

Neill, W.T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 444–450.

Neumann, O. (1986). *How automatic is Stroop interference?* (Report No. 109/1986). Bielefeld: University of Bielefeld, Research Group on Perception and Action.

Neumann. O. (1987). Beyond capacity: a functional view of attention. In H. Heuer & A.F. Sanders (Eds.), *Perspectives on Perception and Action* (pp. 361–394). Hillsdale, N.J.: Lawrence Earlbaum.

Pashler, H.E. (1997). *The psychology of attention*. Cambridge, MA: MIT Press.

Phaf, R.H., Van der Heijden, A.H.C., & Hudson, P.T.W. (1990). SLAM: A connectionist model for attention in visual selection tasks. *Cognitive Psychology, 22*, 273–341.

Posner, M.I. & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D.G. Bouwhius (Eds.), *Attention and performance X*. Hillsdayle, NJ: Earlbaum.

O'Regan, J.K., Rensink, R.A., & Clark, J.J. (1999). Change blindness as a result of 'mudsplashes'. *Nature, 398*, 34.

Rensink, R.A. (2001). Change blindness: Implications for the study of attentional and nonattentional processes in vision. *Proceedings of the XII ESCOP and XVIII BPS Cognitive Section Conference Edinburgh, 5–8 September 2001* (p. 186).

Stroop, J.R. (1935/1992). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

(Reprinted in the *Journal of Experimental Psychology: General, 121,* 15–23.)

Theeuwes, J.(1991). Exogenous and endogenous control of attention: the effect of visual onsets and offsets. *Perception & Psychophysics, 49,* 83–90.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37A,* 571–590.

Van der Heijden, A.H.C. (1987). Central selection in vision. In H. Heuer & A.F. Sanders (Eds.), *Perspectives on Perception and Action* (pp. 421–446). Hillsdale, N.J.: Lawrence Earlbaum.

Van der Heijden, A.H.C. (1992). *Selective attention in vision*. New York: Routledge.

Van der Heijden, A.H.C. (1993). The role of position in object selection in vision. *Psychological Research, 56,* 44–58.

Van der Heijden, A.H.C., Hagenaar, R. & Bloem, W. (1984). Two stages in postcategorial filtering and selection. *Memory and Cognition, 12,* 458–469.

De Vries, K.L.M. (1986). Vertrouwdheid van woorden en woordherkenning [Familiarity of words and word recognition]. *Nederlands Tijdschrift voor de Psychologie en haar Grensgebieden, 41,* 295–304.

Yantis, S. & Jonides, J. (1984): Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 601–621.

Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary vs. automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 121–134.