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Role of Gestalt grouping in selective attention: Evidence from the Stroop task

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Selective attention has been intensively studied using the Stroop task. Evidence suggests that Stroop interference in a color-naming task arises partly because of visual attention sharing between color and word: Removing the target color after 150 msec reduces interference (Neumann, 1986). Moreover, removing both the color and the word simultaneously reduces interference less than does removing the color only (La Heij, van der Heijden, & Plooij, 2001). These findings could also be attributed to Gestalt grouping principles, such as common fate. We report three experiments in which the role of Gestalt grouping was further investigated. Experiment 1 replicated the reduced interference, using words and color patches. In Experiment 2, the color patch was not removed but only repositioned (<2º) after 100 msec, which also reduced interference. In Experiment 3, the distractor was repositioned while the target remained stationary, again reducing interference. These results indicate a role for Gestalt grouping in selective attention.

To have control over our actions, our interactions with the external world require mechanisms that selectively designate part of the available sensory information. The fact that humans detect and identify visual objects that are not relevant for a task at hand, or that even disturb the processing of a target object, indicates that selective attention does not work perfectly. Previous research has often used the color–word Stroop task to study the way in which control is exerted and under what conditions control fails. In seminal experiments, Stroop (1935) showed participants cards with color words printed in different ink colors and cards with colored patches. When the participants named the colors, they had more difficulty in naming incongruent stimuli (e.g., saying "green" to the word RED in green ink) than in naming neutral stimuli (e.g., saying "green" to the patch of green). The response latencies were longer and more errors were made when the color and the word information did not match than in the neutral condition. This finding that the word input involuntarily interferes with naming the color is very robust and has been repeated numerous times (see MacLeod, 1991, for a review of the Stroop literature). The Stroop effect demonstrates that irrelevant information may influence selective attention mechanisms.

In the last 2 decades, variants of the standard Stroop task have been used to study the effects of varied exposure durations of target and distractor on selective attention mechanisms. Can separating object attributes, such as color and shape, in time help us ignore irrelevant aspects of a visual scene? This issue is addressed in the present article. First, we will summarize previous research on temporal segregation of target and distractor and will discuss different explanations for the major findings. Then, we will present three experiments that were designed to assess the relative merits of the different explanations. Finally, in the General Discussion section, we will consider the theoretical implications of our results.

In a seminal unpublished study, Neumann (1986) found that when a to-be-named color bar was removed shortly (i.e., 150 msec) after the onset of a color–word Stroop stimulus, the interference effect in naming the color was reduced. This seems counterintuitive: Although only the distractor word remained in the display, responses exhibited less interference from it, as compared with the more standard situation in which both the target and the distractor stayed present until response. Thus, removing the target from the screen helps people ignore irrelevant information.

In a series of experiments investigating color–color interference, La Heij, Kaptein, Kalff, and de Lange (1995) found similar, albeit somewhat contrary, results with regard to the reduced interference effect. They used a variation of the flanker task (Eriksen & Eriksen, 1974), in which a target color bar presented at fixation point was enclosed by color bar distractors immediately to the left and right of the target. In the incongruent condition, the flanker colors were taken from the set of target colors, whereas in the control condition these distractors were white, which was never a target color. The first experiment showed a color–color interference effect for the incongruent stimuli, relative to neutral stimuli. In the next experiment, the target color was changed to white 160 msec after stimulus onset. The color change reduced the amount of color–color interference. In the last experiment, the target was completely removed from the screen 160 msec after stimulus onset. The color removal did not lead to a reduc-

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tion in color–color interference, in contrast to the results of Neumann (1986).

Using color–word Stroop stimuli with words and color bars spatially separated, La Heij, van der Heijden, and Plooij (2001) found that in a color-naming task, the Stroop interference effect decreased when a target color bar was removed 120 msec after stimulus onset. The same applied to a situation in which the target color was changed to white after this exposure duration. In their second experiment, La Heij et al. (2001) showed that reducing the exposure duration of the color per se was not sufficient to obtain a reduction in interference. Stroop interference was larger when the distractor word and the color bar were removed simultaneously after a short delay than when the exposure duration of the color was not altered and only the distractor was removed after 120 msec. Their next two experiments used words written in an ink color—henceforth, *integral* Stroop stimuli, having identical spatial positions for the color and the word. Although, with this kind of stimuli, attention cannot be attracted to the former position of the color (and away from the distractor) by the color offset, the results of these experiments showed that changing the color to white still reduced the magnitude of interference. The last two experiments of La Heij et al. (2001) compared Stroop interference in a situation in which both the target and the distractor were simultaneously removed after a short duration (the short condition) and a situation in which the target color was changed to white after the same duration (the color-replaced condition). A larger amount of interference was obtained in the short condition than in the color-replaced condition. Moreover, the interference in the short condition was less than that in a condition in which the color and the word remained present until response (the continuous condition).

To summarize, the evidence suggests that removing or replacing the color of a color–word Stroop stimulus shortly after stimulus onset reduces interference. Removing both color and word simultaneously reduces interference less than does removing the color only.

Why do people experience less interference from a word distractor in a color-naming task when the to-be-named color target is removed from the display shortly after onset? We will discuss three alternative accounts for this paradoxical exposure duration effect, which stress the importance of (1) the increased spatial selectivity of input selection, (2) the reduced duration of input selection, or (3) the facilitation of attribute selection on the basis of Gestalt grouping principles.

Increased Spatial Selectivity of Input Selection

Both Neumann (1986) and La Heij et al. (1995) argued that when the target color is removed from a display with spatially separated targets and distractors, this abrupt color offset might draw attention toward the former spatial position of the target and away from the distractor word. In this way, the interference from a word would be reduced by redirecting the attentional *spotlight* (Eriksen & Eriksen, 1974; Glaser & Glaser, 1982; Posner, Snyder, & Davidson, 1980; Treisman & Gelade, 1980) to another location. However, La Heij et al. (2001) found also a reduction in the interference effect with *integral* Stroop stimuli. Because the target and the distractor then occupy identical spatial positions, the obtained reduction in interference with these stimuli obviously cannot be explained in terms of relative spatial selectivity of input selection.

Duration of Input Selection

Neumann (1986) proposed that a word's interfering power depends on the amount of attention directed to the target color. In the case of integral color–word Stroop stimuli or the color–color flanker stimuli used by La Heij et al. (1995), the target and the distractor are positioned very close to each other in space. Neumann argued that the inability of the participants to focus attention solely on the target color is the critical factor that is responsible for the processing of the distractor up to the stage where interference is located. In other words, when the target and the distractor are physically located close to each other, as long as attention is focused on the target color, the interfering distractor input is also being processed unintentionally (we termed this the *Trojan horse effect*; see Roelofs & Lamers, 2007). This results in slower responses for incongruent stimuli than for neutral stimuli. However, as soon as the target color is removed from the display, the amount of attention directed to this target diminishes rapidly. Such a terminated input selection ends the parasitic attention sharing between the target and the distractor and, thus, reduces the Stroop interference. In the remainder of this article, we will refer to this account as the *duration* explanation.

The last two experiments of La Heij et al. (2001) provided some evidence against Neumann's (1986) account in terms of the duration of input selection. The account predicts no difference between a situation in which both the target and the distractor are simultaneously removed after a short duration and a situation in which the target color is changed to white after the same duration (the color-replaced condition). Instead, La Heij et al. (2001) found a larger amount of interference in the short condition than in the color-replaced condition. Therefore, they concluded that the reduced interference effect does not stem solely from the target color offset. Instead, they proposed that the reduction is due to the breaking of *Gestalt grouping*.

Facilitation of Attribute Selection on the Basis of Gestalt Principles

According to Gestalt psychology (Wertheimer, 1923), there are several principles by which groups of stimuli organize themselves preattentively in perception. One of them is the principle of proximity, which states that spatially close objects tend to be grouped together (e.g., Han, Humphreys, & Chen, 1999). It is possible that for integral color–word Stroop stimuli such as those used by La Heij et al. (2001), where the color and the word share the same spatial location, the target and the distractor are perceived as constituting two attributes (color and word form) of the same object. If attention is given to a certain object, all features of that object are processed automatically (Blaser, Pylyshyn, & Holcombe, 2000; Duncan, 1984; Kahneman & Chajczyk, 1983; Kahneman & Henik, 1981; O'Craven, Downing, & Kanwisher, 1999; Wühr & Waszak, 2003).

Thus, by directing attention to the Stroop stimulus for processing of the target color attribute, the word (form attribute) is processed as well. If the color is removed after a certain time interval, this Gestalt principle is broken, and the color and the word are no longer seen as belonging to one object, so that early attentional disengagement of the word occurs. Although only the distractor word remains in the display after the target color has disappeared, this information is no longer processed, and the interference effect in naming the color is reduced. We refer to this account as the *Gestalt* explanation. According to La Heij et al. (2001), "this account is rather speculative and in need of further empirical support" (p. 631).

The main objective of the present study was to further examine the Gestalt account of the reduction in Stroop interference. To differentiate between the duration and the Gestalt explanations, our approach was to compare performance in two color–word Stroop conditions: a more or less standard condition and a situation in which the Gestalt grouping is broken while target exposure duration is held constant. One way to create such a situation is by spatially separating the target and the distractor after a short delay. Wertheimer (1923) introduced the notion of a *Gestalt principle of common fate*: Elements that appear to move simultaneously in the same direction with the same speed are perceived as belonging to a single object (Han et al., 1999; Lee & Blake, 2001; Stürzel & Spillmann, 2004; Uttal, Spillmann, Stürzel, & Sekuler, 2000). If one element moves away while the other remains stationary, this breaking of the common fate will disturb a Gestalt grouping. The target exposure duration, on the other hand, is not altered by this operation, because the target does not disappear from the screen. Thus, when the color and the word are spatially separated, the duration account does not predict a reduction in interference, as compared with the situation in which both the color and the word remain stationary, whereas the Gestalt theory predicts less interference because the perceived attribute grouping is broken. However, the approach just described could not be followed with integral Stroop stimuli, because color and form then cannot be physically separated. Instead, in our experiments, we used color bars with a distractor word superimposed on it, which we will refer to as *semi-integral*.

We conducted three experiments to examine the role of Gestalt grouping principles in selective attention. The first experiment confirmed that by reducing the target presentation time, a decrease in Stroop interference effect is also obtained with semi-integral Stroop stimuli. The second experiment was designed to differentiate between the duration of input selection and the Gestalt accounts as explanations for the finding in Experiment 1. The third experiment tested and refuted a possible alternative explanation for the results of Experiment 2 in terms of automatic attention capturing by items that are moving.

EXPERIMENT 1

The first experiment was conducted to replicate the finding of La Heij et al. (2001, Experiment 1) that for incongruent color–word Stroop stimuli, responses are faster when the target is removed shortly after stimulus onset, as compared with a standard situation in which the target remains in the display together with the distractor. For the neutral stimuli, we predict no difference in mean reaction times (RTs) between these two exposure conditions.

Method

Participants. Twenty-six students (21 of them female) from Radboud University Nijmegen volunteered to participate in the experiment. Their age varied from 18 to 33 years, with a mean of 23 years. All had normal or corrected-to-normal vision. The participants took part individually and were paid for their participation.

Apparatus. The experiment was conducted on two separate, connected microcomputers. The first computer generated the visual displays; the second computer collected the experimental data. A voice key measured the vocal naming latencies with an accuracy of 1 msec (1000 Hz). The participants were seated in front of a color monitor connected to the first computer, at a viewing distance of approximately 70 cm. On a second monitor connected to the data collection computer, the experimenter observed the correct response and the participant's response latencies.

Stimuli and Design. The displayed stimuli consisted of colored rectangular bars and written distractor color words. The stimuli were 21×61 mm (corresponding to $1.72° \times 4.98°$ of visual angle at a viewing distance of approximately 70 cm). The stimuli consisted of red, green, and blue target bars and the following Dutch color words: ROOD (*red*), GROEN (*green*), and BLAUW (*blue*). The distractor words were superimposed in white uppercase letters on the color bar. The background of the computer screen was black.

Two distractor conditions were used: neutral and incongruent, each having three different stimuli. The neutral stimuli resulted from the three color bars with an XXXXX string superimposed on it. With the incongruent stimuli, for each color bar only one nonmatching distractor word was used (red patch–BLAUW, green patch–ROOD, and blue patch–GROEN).

Two exposure conditions were used: a *continuous* condition (both the target and the distractor remained present until the end of the trial) and a *color-removed* condition (the target color bar disappeared after 100 msec). In the experiment, each of these 12 trial combinations (6 stimuli $\times$ 2 exposure times) was presented 30 times, yielding a total of 360 trials per participant (90 trials per condition). The presentation of the stimuli was randomized within a block of 12 trials, with a short break after every 72nd trial.

Procedure. The participants took part individually in a dimly illuminated, quiet room. The instruction was given on paper and summarized vocally by the experimenter. Before the actual experiment started, the participants received 12 practice trials. Then, five experimental blocks followed. When the color–word Stroop stimulus appeared, the color had to be named aloud. The participants were encouraged to react as quickly and accurately as possible, while trying to ignore the distractor word.

A trial had the following structure. A semi-integral color–word Stroop stimulus appeared at the center of the screen. The distractor word always remained present until the participant made a vocal response or until a time-out occurred at 1,500 msec. The target color bar either stayed on the screen until response (in the continuous condition) or disappeared after 100 msec (in the color-removed condition). Rows a and b of Figure 1 illustrate the conditions. When the response was made, the screen blanked for 1 sec, after which the next trial started. The beginning of a break was indicated by the Dutch word PAUZE (*pause*) for 1,500 msec, whereas the next block was preceded by the word ATTENTIE (*attention*). An experimental session took about 30 min.

Results

The data of 2 participants were excluded from analysis, because they exceeded our 5% incorrect response criterion. For the data of the remaining 24 participants, the

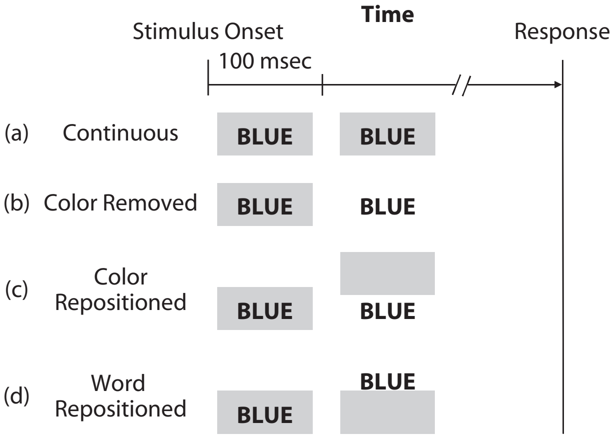

Figure 1. Schematic examples of the four exposure conditions used in the experiments. The gray bar represents a red colored patch (in the experiments, we used the colors red, green, and blue). In the continuous condition (Experiments 1–3), the initial display remained the same until a vocal response was given or a time-out occurred. In the color-removed condition (Experiment 1), the color bar disappeared after 100 msec. In the color-repositioned condition (Experiment 2), the color bar was relocated to a position a little above or below the distractor word. In the word-repositioned condition (Experiment 3), the distractor word was relocated to a position a little above or below the color bar. In all the experiments, the distractor words were written in the participants' native language (Dutch).

following data-trimming procedure was used: RTs longer than 1,500 msec, RTs shorter than 100 msec, RTs for trials on which the voice key malfunctioned or triggered inappropriately (in combination, 1.8% of the data), and RTs for trials on which the participant made an incorrect response (1.6% of the data) were discarded. The remaining RTs were used in calculations of means. Table 1 shows the mean RTs and error percentages obtained in the experimental conditions.

A repeated measures ANOVA was performed on the mean correct RTs, with distractor condition (incongruent vs. neutral) and exposure condition (continuous vs. color removed) as within-participants variables. The analysis showed a main effect of distractor condition [$F(1,23) = 134.3$, $MS_e = 1{,}083$, $p < .001$, reflecting an average Stroop interference effect of 78 msec] and a main effect of exposure condition [$F(1,23) = 16.4$, $MS_e = 287$, $p = .001$] (mean response latencies were, overall, 14 msec shorter in the color-removed condition than in the continuous condition). The Stroop interference was larger in the continuous condition (86 msec) than in the color-removed condition (70 msec) [$t(23) = 2.38$, $p = .01$, one-tailed].

Table 1
Mean Reaction Times (RTs, in Milliseconds; With Standard Deviations), Error Percentages, and Stroop Interference Effects (Incongruent Minus Neutral) in the Distractor and Exposure Conditions in Experiment 1

	Exposure					
	Continuous			Color Removed		
	RT			RT		
Distractor	*M*	*SD*	E%	*M*	*SD*	E%
Incongruent	676	168	4.6	654	160	4.5
Neutral	590	133	2.3	584	126	2.5
Stroop effect	86		2.3	70		2.0

Subsequent analyses were performed to further investigate this effect. As was predicted, for incongruent stimuli, responses were significantly faster in the color-removed condition than in the continuous condition [$t(23) = 14.1$, $p = .001$]. In contrast, again as predicted, for neutral stimuli there was no difference in RTs between the two exposure conditions [$t(23) = 2.0$, $p = .17$].

Although the number of incorrect responses was very small in this experiment, a repeated measures ANOVA was performed on them. Significantly more errors were made in the incongruent condition than in the neutral condition [$F(1,23) = 12.61$, $p = .002$]. The number of errors in the continuous condition was equal to the number of errors in the color-removed condition ($p > .90$). The interaction between distractor condition and exposure condition also was not significant ($p > .60$). Thus, most errors were made in the slowest condition. We conclude that there was no speed–accuracy trade-off in the data.

Discussion

Experiment 1 confirms and extends the finding from Neumann (1986) and La Heij et al. (2001): Removing the to-be-named color from a color–word Stroop stimulus shortly after stimulus onset actually improves the participant's ability to name that color. Thus, segregation of a target and a distractor in time seems to help visual attention. Apparently, this finding is not confined to separated color–word Stroop stimuli (La Heij et al., 2001, Experiments 1 and 2; Neumann, 1986) and integral color–word stimuli (La Heij et al., 2001, Experiments 3–6; Neumann, 1986) but also applies to semi-integral stimuli (color word presented on top of a colored patch).

EXPERIMENT 2

In all the experimental conditions of our first experiment, the distractor word stayed present on the screen until response and could exert its influence. Nevertheless, the participants responded more quickly and more accurately to a visual target when this target disappeared after 100 msec. What is the reason for this paradoxical exposure duration effect? According to the duration account, in the color-removed condition, the disappearance of the target terminates the parasitic attention sharing between the target and the distractor and, thus, reduces the interference from the word. Alternatively, the Gestalt account states that the offset of the target color breaks the Gestalt grouping, and as a result, participants no longer perceive the target and the distractor as belonging to a single object. Word form information is then not automatically processed together with the color attribute (Blaser et al., 2000; Duncan, 1984; Kahneman & Chajczyk, 1983; Kahneman & Henik, 1981; Kanwisher & Wojciulik, 2000; O'Craven et al., 1999), resulting in a reduction of Stroop interference in the color-removed condition. To test which of these two explanations is correct, the target exposure duration (and thereby, the amount of parasitic attention sharing) should be kept fixed, whereas at the same time the Gestalt grouping should be broken. This was done in Experiment 2 by letting the color bar and the distractor word move away from each other. To ensure that both components stayed in the same attention area, the movement was restricted to a very small (<2º) visual angle (Gatti & Egeth, 1978; Hagenaar & van der Heijden, 1986; Wühr & Waszak, 2003).

Our hypotheses are as follows. If the reduction in Stroop interference in Experiment 1 was due to parasitic attention sharing between color and word during input selection, moving items around in the display should not influence the level of interference, as long as both the target and the distractor stay within the same attentional area and the stimuli letters are large enough to minimize the effect of reduced visual acuity (Merikle & Gorewich, 1979). The target exposure duration was kept constant in this second experiment. Therefore, the amount of interference should not differ between a situation in which the target moves away from the distractor after a short period (the *color-repositioned* condition) and the situation in which both the target and the distractor remain stationary (the *continuous* condition).

Alternatively, features that have a common fate in sharing the same motion direction are perceptually organized as one entity (Lee & Blake, 2001; Stürzel & Spillmann, 2004; Uttal et al., 2000). Physically separating the target and the distractor will break such a Gestalt grouping. Consequently, if the reduction in Stroop interference found in Experiment 1 arose from help in attribute selection, we predict that physically separating the two attributes will cause the distractor to be processed to a lesser extent. As in Experiment 1, the amount of Stroop interference in the color-repositioned condition will then be smaller than that in the continuous condition.

In short, if the data from Experiment 2 show no difference in the amount of interference between the continuous and the color-repositioned conditions, breaking the common fate had no effect, and the duration explanation receives some extra support for being responsible for the effect in Experiment 1. In contrast, if a difference in interference between the two exposure conditions is found, the duration account cannot explain this finding, whereas the Gestalt account can.

Method

Participants. Sixteen students (11 of them female) from Radboud University Nijmegen volunteered to participate in the experiment. Their age varied from 20 to 29 years, with a mean of 22 years. All had normal or corrected-to-normal vision. The participants took part individually and were paid for their participation. None of them had participated in the previous experiment.

Apparatus, Stimuli, Procedure, and Design. The apparatus, visual stimuli, and procedure used in this experiment were identical to those in Experiment 1. The design was similar to that in the previous experiment, except for the following difference: Instead of removing the target from the screen, in this second experiment the target was spatially repositioned. At the start of each trial, the target color bar and the distractor word appeared at the center of the screen. In the continuous condition, both of them stayed there until response. In the color-repositioned condition, the target was randomly relocated after 100 msec to a location a little above or below the central position, whereas the distractor word remained stationary. The center-to-center distance between the color bar and the (invisible) rectangle in which the distractor word was presented was 21 mm (1.72º at a viewing distance of approximately 70 cm). Since the rectangles were presented adjacent to one another, the interstimulus distance approached zero. Rows a and c of Figure 1 illustrate the conditions.

Results

RTs were treated in the same way as in Experiment 1. The 100-msec criterion, the 1,500-msec criterion, and the trials on which the voice key malfunctioned or triggered inappropriately accounted for 0.7% of the data. Also, RTs for trials on which the participant made an incorrect response (1.3% of the data) were discarded. The remaining RTs were used in calculations of means. Table 2 shows the mean RTs and error percentages obtained in the various experimental conditions in Experiment 2.

A repeated measures ANOVA was performed on the mean correct RTs, with distractor condition (incongruent vs. neutral) and exposure condition (continuous vs. color repositioned) as within-participants variables. The analysis showed a main effect of distractor condition [$F(1,15) = 59.38$, $MS_e = 67,048$, $p < .001$]. This reflects an average Stroop interference effect of 65 msec. There was no main effect of exposure condition ($p > .4$). Thus, overall, mean RTs were not significantly different in the continuous condition (627 msec) and the color-repositioned condition (631 msec). The Stroop interference effect was larger in the continuous condition (83 msec) than in the color-repositioned condition (47 msec) [$t(15) = 4.19$, $p = .001$].

Subsequent analyses were performed to investigate this effect. For incongruent stimuli, responses differed significantly in the two exposure conditions [$t(15) = 4.67$, $p < .05$]. The mean RT in the color-repositioned condition was 14 msec shorter than that in the continuous condition. For neutral stimuli, responses also differed significantly between the two exposure conditions [$t(15) = 17.01$, $p = .001$]. The mean RT in the color-repositioned condition was 22 msec longer, as compared with the continuous condition.

A repeated measures ANOVA was performed on the incorrect responses. Significantly more errors were made in the incongruent condition than in the neutral condition [$F(1,15) = 20.4$, $p < .001$], mirroring the RT pattern. The main effect of exposure condition and the distractor × exposure interaction were not significant (ps > .25). Thus, no trace of a speed–accuracy trade-off was found.

Discussion

Experiment 2 shows again a reduction in Stroop interference: When naming the color from a semi-integral

Table 2
Mean Reaction Times (RTs, in Milliseconds; With Standard Deviations), Error Percentages, and Stroop Interference Effects (Incongruent Minus Neutral) in the Distractor and Exposure Conditions in Experiment 2

	Exposure					
	Continuous			Color Repositioned		
	RT			RT		
Distractor	*M*	*SD*	E%	*M*	*SD*	E%
Incongruent	668	160	3.2	654	134	2.5
Neutral	585	120	1.2	607	119	1.0
Stroop effect	83		2.0	47		1.5

color–word stimulus, participants suffered less interference from the distractor word when the target color bar was repositioned after 100 msec than when the stimuli remained stationary. Thus, a reduced interference effect was obtained by separating the target and the distractor not only temporally (Experiment 1), but also spatially (Experiment 2). This seems to rule out the possibility that duration was (solely) responsible for the faster responses in the color-repositioned condition. After all, the duration of target input was held constant between the two exposure conditions. The Gestalt account, on the other hand, can explain the results by stating that the physical separation of the color and the word broke the perceptual grouping, so that less attention was given to the word.

Considering the data, a second pattern is evident: In contrast to Experiment 1, the RTs in the neutral condition in the present experiment were not the same for the two exposure conditions. The mean response time for a neutral xxxxx distractor was 22 msec longer in the color-repositioned condition than in the continuous condition. This indicates that the task in this second experiment was more difficult than that in Experiment 1. Repositioning the color bar somehow disturbed the perception process. If the repositioning of the color increased response latencies in the neutral condition, it seems logical that it also increased RTs in the incongruent condition. This suggests that for incongruent stimuli, the reduction in RT caused by the target–distractor separation was, in fact, even stronger but was partly undone by an RT increase caused by the extra task difficulty. The observed reduction of 14 msec in the incongruent condition could thus be the combined effect of two different sources—namely, a 36-msec *reduction* caused by the stimulus segregation and a 22-msec *increase* caused by the perceptual difficulty.

To investigate our hypothesis that the response latencies for incongruent stimuli in the color-repositioned condition resulted from two sources with opposite effects, we examined the latency distributions of the responses. When the perceptual difficulty caused by the repositioning of the color prolonged the color-naming response (as indicated by the longer mean RT for neutral stimuli in the color-repositioned condition, as compared with the continuous condition), we expected this perceptual difficulty effect to be present across the whole latency distribution for both neutral and incongruent stimuli. Yet, for incongruent stimuli, the stimulus segregation had an opposite effect, causing the mean RT in the color-repositioned condition to be shorter than that in the continuous condition. Earlier research indicated that the interference effect in a conflict task varied with RT (De Jong, Berendsen, & Cools, 1999; Ridderinkhof, 2002). For example, the amount of Stroop interference was often larger for slow responses than for fast responses. Therefore, it is conceivable that the interference reduction effect stemming from the Gestalt breaking had a larger influence for slow responses than for fast responses. Such opposite effects on task performance in the incongruent condition should be observable in plots of latency distributions.

To obtain the latency distributions, we divided the rank-ordered response latencies for each participant into deciles (10% quantiles) and computed mean latencies for each decile, separately for incongruent and neutral stimuli and for continuous and color-repositioned conditions. By averaging these decile means across participants, so-called Vincentized cumulative distribution functions are obtained (Ratcliff, 1979). Vincentizing the latency data across individual participants provides a way of averaging data while preserving the shapes of the individual distributions. Figure 2 shows the distributional plots for the neutral and incongruent conditions.

The two left-hand curves in Figure 2 show the latency distributions for the neutral stimuli in the continuous and color-repositioned conditions. The figure shows that the disturbance effect from repositioning the target color bar was present throughout the entire latency range. Statistical analysis revealed that there were effects of exposure condition [$F(1,15) = 17.06$, $p = .001$] and decile [$F(9,135) = 373.79$, $p < .001$]. Exposure condition and decile did not interact ($p > .55$), confirming that the disturbance effect was independent of latency.

The two right-hand curves in Figure 2 show the latency distributions for the incongruent stimuli in the continuous and color-repositioned conditions. The figure shows that up to the fourth decile, latencies are actually longer in the color-repositioned than in the continuous condition, which we attribute to the disturbance effect of the moving item. However, above the fourth decile, response latencies are shorter in the color-repositioned than in the continu-

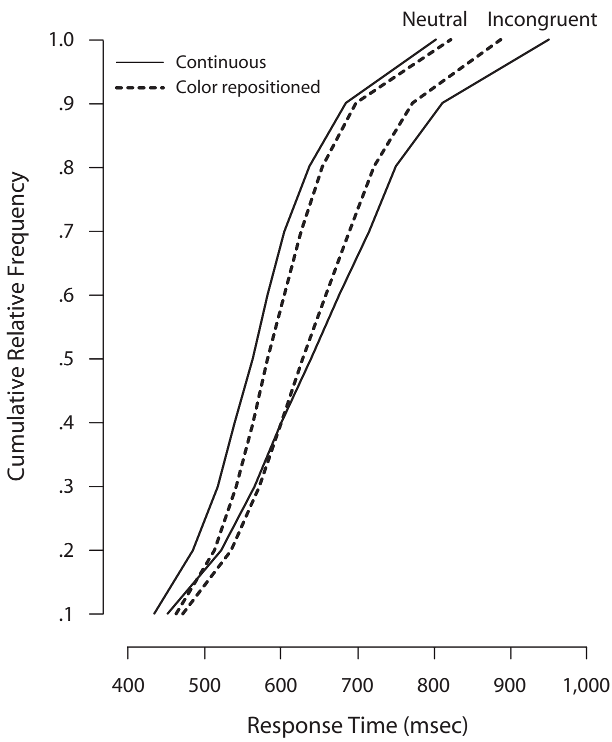

Figure 2. Vincentized cumulative distribution curves for the color-naming latencies in response to semi-integral color–word Stroop stimuli for the neutral stimuli and incongruent stimuli in the continuous and color-repositioned conditions in Experiment 2.

ous condition, which we attribute to the Gestalt-breaking process. Statistical analysis revealed that there were effects of exposure condition [$F(1,15) = 4.66$, $p < .05$] and decile [$F(9,135) = 336.74$, $p < .001$]. Importantly, exposure condition and decile interacted [$F(9,135) = 11.33$, $p < .001$], which provides support for our hypothesis about two opposing effects.

To conclude, analyses of the latency distributions indicate that (only) for incongruent stimuli, two separate processes interact, which strongly suggests that the reduction of the distractor effect caused by the target–distractor separation was actually stronger than the mean RTs suggested. On the one hand, breaking the Gestalt reduced the amount of Stroop interference, an effect that became stronger with increasing response latency. On the other hand, responses were slowed down by the disturbance caused by a moving item in the display. This effect, which is independent of response latency, works against the Gestalt breaking effect.

EXPERIMENT 3

Although the results of our second experiment strongly favor the Gestalt account over the duration account, one could interpret the data in terms of another attentional process involved in (visual motion) perception. In our first experiment, both the target and the distractor remained static, whereas in the second experiment, one of the stimulus attributes (the color) moved in half the trials. Previous research has shown that moving items and abrupt onsets can capture attention in an automatic fashion (Brown, Gore, & Carr, 2002; Folk, Remington, & Wright, 1994; Hillstrom & Yantis, 1994; Miller, 1989; Tipper, Brehaut, & Driver, 1990; Yantis & Hillstrom, 1994). Therefore, in the color-repositioned condition, more attention could have been given to the moving item than to the stationary item. As the moving item was always the to-be-named color bar, this could also explain the reduced interference effect in the second experiment (but not in Experiment 1). Thus, to establish that it is really the breaking of a Gestalt grouping in attribute selection that causes the observed paradoxical exposure duration effect, we have to exclude automatic capture of attention by movement as a competing alternative.

We designed Experiment 3 for this purpose by simply changing the movement factor. In the *word-repositioned* condition, the target always remained stationary, whereas the *distractor* moved. As in Experiments 1 and 2, in the continuous condition, both the target and the distractor remained stationary. The rationale is straightforward: If the moving attribute (the word) automatically receives more attention than the static attribute (the color), *more* Stroop interference should be observed in the word-repositioned condition than in the continuous condition. In contrast, facilitation of attribute selection by breaking the Gestalt grouping process predicts results similar to those in Experiment 2: The word-repositioned condition should show a reduction in Stroop interference. If attributes are physically segregated, participants will no longer perceive them as belonging to a single object, regardless of which attribute is moving. Note that in this third experiment, there was again a moving item present in the display that could disturb the task at hand, thereby prolonging RTs in the word-repositioned condition.

Method

Participants. Sixteen students (14 of them female) from Radboud University Nijmegen served as paid participants. Their age varied from 18 to 26 years, with a mean of 22 years. All had normal or corrected-to-normal vision. The participants took part individually, and none had participated in the earlier experiments.

Apparatus, Stimuli, Procedure, and Design. The apparatus, stimuli, and procedure used in this experiment were identical to those in Experiment 1. The design was very similar to that in Experiment 2. Only the movement factor was reversed. At the start of each trial, the target color bar and the distractor word appeared at the center of the screen. In the continuous condition, both of them stayed there until response. In the word-repositioned condition, 100 msec after stimulus onset, the distractor word was relocated to a location a little above or below the central position, whereas the target color bar remained stationary. As in Experiment 2, the center-to-center distance was 1.72º at a viewing distance of 70 cm, whereas the interstimulus distance was virtually zero (adjacent rectangles). Rows a and d of Figure 1 illustrate the conditions.

Results

The data were treated in the same way as in the previous experiments. RTs longer than 1,500 msec, RTs shorter than 100 msec, RTs for trials on which the voice key malfunctioned or triggered inappropriately (in combination, 0.6% of the data), and RTs for trials on which the participant made an incorrect response (1.7% of the data) were discarded. The remaining RTs were used in calculations of means. Table 3 shows the mean RTs and error percentages obtained in the experimental conditions.

A repeated measures ANOVA was performed on the mean correct RTs, with distractor condition (incongruent vs. neutral) and exposure condition (continuous vs. word repositioned) as within-participants variables. The analysis showed a main effect of distractor condition [$F(1,15) = 145.29$, $MS_e = 67{,}498$, $p < .001$]. This reflects an average Stroop interference effect of 65 msec. There was no main effect of exposure condition ($p = .12$). Thus, overall, mean RTs were not significantly different in the continuous condition (590 msec) and the word-repositioned condition (597 msec). The Stroop interference was larger in the continuous condition (71 msec) than in the word-repositioned condition (59 msec) [$t(15) = 1.80$, $p = .05$].

Subsequent analyses were performed to investigate this effect. For incongruent stimuli, responses did not differ in

Table 3
Mean Reaction Times (RTs, in Milliseconds; With Standard Deviations), Error Percentages, and Stroop Interference Effects (Incongruent Minus Neutral) in the Distractor and Exposure Conditions in Experiment 3

	Exposure					
	Continuous			Word Repositioned		
	RT			RT		
Distractor	*M*	*SD*	E%	*M*	*SD*	E%
Incongruent	625	148	4.0	626	135	4.0
Neutral	554	112	1.4	567	111	1.4
Stroop effect	71		2.6	59		2.6

the two exposure conditions ($p > .70$). For neutral stimuli, mean RT in the word-repositioned condition was 13 msec longer than that in the continuous condition [$t(15) = 10.7$, $p = .005$].

A repeated measures ANOVA was performed on the incorrect responses. Significantly more errors were made in the incongruent condition than in the neutral condition [$F(1,15) = 10.1$, $p < .01$], mirroring the RT pattern. The main effect of exposure condition and the distractor × exposure interaction were not significant (ps > .05). Thus, again, no trace of a speed–accuracy trade-off was found.

Discussion

Recall that in Experiment 2, we found a reduction in Stroop interference when the target color bar was repositioned shortly after stimulus onset, when compared with a situation in which both the target and the distractor remained fixated. We argued that this reduction is obtained by facilitation of attribute selection (the Gestalt account). Experiment 3 was set up to exclude a competing explanation according to which a moving item automatically attracts attention. If the target moves (Experiment 2), this should direct attention to the target and reduce interference from the distractor, whereas in the situation in which the distractor moves (Experiment 3), the extra attention given to the moving distractor will increase the interference. However, the present results show that even when it is the distractor attribute that moves after 100 msec, there is a trend toward a *reduction* in Stroop interference (the interference effect was 12 msec smaller in the word-repositioned condition than in the continuous condition). Therefore, we can safely exclude this alternative explanation in terms of automatic attentional capture for moving items. The Gestalt account can explain the results of all three experiments.

Note that the RTs in the neutral condition were 13 msec longer in the word-repositioned condition than in the continuous condition. This indicates that although the target always appeared at the center of the screen, the moving item again disturbed the color-naming task in the word-repositioned condition. Following our rationale from Experiment 2, this could mean that for incongruent stimuli, the obtained RTs again reflected a combined effect. On one hand, the response latencies were reduced by the target–distractor separation, but on the other hand, this reduction was undone by the 13-msec increase caused by the extra task difficulty. Although interesting, it is not important for the present purpose. The main point of Experiment 3 is that the Stroop interference was obviously not *increased* in the word-repositioned condition, as the to-be-excluded alternative account would predict.

GENERAL DISCUSSION

Previous research on color naming with Stroop-like stimuli has suggested that the distractor "steals" less attention when the target is removed from the display shortly after stimulus onset than when it remains on the screen until response (La Heij et al., 1995; La Heij et al., 2001; Neumann, 1986). Apparently, the human attentional control system performs better with such a temporal segregation of stimulus attributes. Three theoretical accounts have been proposed to explain this paradoxical exposure duration effect: the increased spatial selectivity of input selection, duration of input selection (parasitic attention sharing), and facilitation of attribute selection on the basis of Gestalt principles. In the present study, we set out to determine the relative merits of these explanations. Here, we will discuss our experimental results and their implications for our understanding of visual attention.

In earlier research, the paradoxical effect was obtained with color–color stimuli (La Heij et al., 1995), separated color–word Stroop stimuli (La Heij et al., 2001, Experiments 1 and 2; Neumann, 1986), and integral color–word stimuli (La Heij et al., 2001, Experiments 3–6; Neumann, 1986). In our first experiment, we established that the paradoxical exposure duration effect could also be replicated with semi-integral color–word Stroop stimuli. Interference from the word distractor was less in the color-removed condition (the target color bar disappeared after 100 msec) than in the continuous condition (the target and distractor remained visible until the end of the trial). In our second experiment, we showed that this reduction in interference is also obtained when the target is spatially repositioned shortly after stimulus onset (a little above or below the starting position). The duration account cannot explain this, because the target remains present within the attended small spatial area (Gatti & Egeth, 1978; Hagenaar & van der Heijden, 1986; Merikle & Gorewich, 1979). In contrast, the results are in accordance with the predictions from the Gestalt account: When the target and the distractor are separated, they are no longer perceived as one entity, and the distractor input is not automatically processed together with the target information. The results of our third experiment excluded the possibility that attentional capture by the moving item was responsible for the effect in Experiment 2. Even in a condition in which the distractor was moving, we observed that the amount of interference from that distractor was less than that in a situation in which both the target and the distractor remained stationary.

One might argue that the observed data patterns of Experiments 2 and 3 simply result from a difference in visual configuration, an artifact in the design. At the start of each experimental trial, color and word were presented at the same location. In half the trials, one of the features was repositioned after 100 msec to a new location, while the other feature remained at its initial position. If one holds the belief that the human attentional system is not performing any task during these first 100 msec, one might claim that the continuous condition represents a different class of Stroop stimuli (semi-integral) than do the color-repositioned and word-repositioned conditions (spatially separated Stroop stimuli). Previous research has suggested that increasing the spatial distance between a word and a color bar reduces Stroop interference and that, therefore, a separated stimulus exhibits less interference than does a semi-integral stimulus (Brown, 1996; Brown, Roos-Gilbert, & Carr, 1995; Kahneman & Henik, 1981; MacLeod, 1998; Neumann, 1986, Experiments 2 and 3), similar to our data patterns in Experiments 2 and 3.

However, for the following reasons, we do not believe that the reduced interference effects in our experiments arose from such a difference in visual configuration. First, a possible deviation in visual configuration cannot explain the finding in Experiment 1, in which no separated Stroop stimuli were presented. Second, it is unlikely that our perceptual system idly waits for 100 msec before it starts interpreting the surrounding environment. Rather, as soon as a color–word stimulus appears in a display, the visual system starts by identifying the target color and separating the display into figures and ground. Earlier research has shown that relationships between objects are especially crucial within the first 100 msec after onset. For example, maximal impact of incongruent words in color naming is empirically observed when the words appear within 100 msec of the colors (Glaser & Glaser, 1982). Moreover, our error patterns indicate that the target color is, in fact, very reliably visually identified on the basis of the sensory information available within the first 100 msec and that incorrect responses arise mainly from distractor interference.

Third, even when the visual system does not process the stimulus during the first 100 msec and the distractor conditions do indeed correspond to different Stroop stimuli classes (integral in the continuous condition vs. separated in the movement conditions), the situation is unclear. As Blaser et al. (2000) stated, "location and 'objecthood' can be difficult to distinguish, as typically a single object occupies a single location" (p. 196). Indeed, with the present stimuli, it is hard to directly investigate to what extent such difference in visual configuration would contribute to the decrease in interference. After all, direct comparison of these two classes of Stroop stimuli confound visual configuration (location) with Gestalt grouping (two objects vs. one object).

In the Stroop literature with separated stimuli, a variety of different distances between color and word have been tested. Gatti and Egeth (1978) increased the spatial distance between the color and the word from 1º to 5º. They observed that interference diminished from 90 to 40 msec. However, they did not include a direct comparison with an integral stimulus. Moreover, the difference in distance (1º–5º measured from color bar edge to word edge) was much greater than ours (close to 0º). As was mentioned before, Merikle and Gorewich (1979) observed no decrease of Stroop interference with an increase in distance from 0.5º to 2.5º when letter size was increased to compensate for acuity loss. Their letters extended 0.57º of vertical angle at a distance of 2.5º, whereas our letter size is 1.72º at a distance close to 0º. Therefore, it seems implausible that the reduced Stroop interference in our color-repositioned condition simply stemmed from a reduced visual acuity in that condition (see also Hagenaar & van der Heijden, 1986).

MacLeod (1998) found decreased interference for separated stimuli, as compared with integral color–word stimuli. However, these stimuli (a row of colored asterisks appearing just above a color word in white) differed much from the ones we used. Brown et al. (2002) presented color patches and words at different locations. Before stimulus onset, the location of either the color patch or the word was cued. Manipulation of the locus of attention modulated the magnitude of Stroop interference. Stroop interference was larger when the locations of the color and the word were close together than when they were far apart (13º) and attention was drawn to the location of the color patch. Yet, again, the distances used were much greater than that in our study. Brown, Gore, and Pearson (1998) investigated differential visual half-field Stroop effects. They found that physical integration of the word and color stimuli was not necessary to the effect and that—in contrast with many of the earlier findings—Stroop effects were larger when color targets and color names were in different visual eye fields than when they were at the same location. Moreover, they stated that in all the studies in which increasing spatial separation between the word and the color target reduced Stroop interference, the color targets were presented at a fixated location known in advance to the participant and constant across trials. When target location is uncertain (as in our Experiment 2), increasing the interstimulus distance only marginally effects the level of interference.

In the Stroop literature, a variety of different distances between color and word have been tested, but the situation is complicated. We maintain that even in the unlikely case that the participants ignored the first 100 msec of stimulus presentation, it is not obvious that our data pattern resulted merely from a difference in visual configuration.

We argued that separating the color and the word either in time or in space hampers their integration into a single percept according to Gestalt principles. Can feature binding into one object really be prevented within the short time frame of 100 msec? We think it can, at least partly. Schoenfeld et al. (2003) combined event-related potentials, event-related magnetic fields, and functional magnetic resonance imaging data to study the time course of the rapid perceptual integration of multifeature objects (moving-dot arrays). On the basis of their findings, they concluded that "this spatiotemporal analysis found that an irrelevant feature (color) was activated in its specialized cortical module within a few tens of milliseconds after initial registration, rapidly enough to provide a mechanism for the binding and perceptual integration of the multiple features of an attended object" (Schoenfeld et al., 2003, p. 11806). They estimated that the time needed for feature selection and binding processes to be completed lies around 230–250 msec after stimulus onset. In our experiments, it is therefore likely that separating the color and the distractor features after 100 msec disturbed the binding process.

To conclude, our results demonstrate a role for Gestalt grouping principles in selective attention. Our research replicated earlier observations that Stroop interference is reduced when the color is removed shortly after stimulus onset. This paradoxical exposure duration effect with semi-integral color–word stimuli appears to reflect facilitation of attentional selection. It cannot be accounted for by terminated input selection (the duration account), because even when the target was only repositioned while remaining perfectly visible, a reduction in Stroop interference was observed. The facilitation of attribute selection can explain all the present results by presuming that when the color and the word form are separated (either temporally or spatially), a grouping process based on Gestalt principles is disturbed. If the attributes are not seen as belonging to a single entity, the distractor input is not processed along with the target. We conclude that the human attentional system can exploit dynamic information changes during stimulus processing (causing early attentional disengagement) to guide and control attention in conflicting situations.

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