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Effect of Abrupt Onsets Attentional Capture by the Color Word in the Stroop Task*

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Although the Stroop effect has been considered to be strong evidence of automatic recognition of word, some studies showed that the Stroop effect is modulated by visual attention. In this study, we investigated the role of visual attention in the involuntary word processing of the Stroop task. Three experiments examined whether the magnitude of the Stroop effect is modulated by the color-word's ability to capture attention in a bottom-up fashion, namely, via an abrupt onset. The Stroop effect was found to be smaller when the color-word distractor appeared as a part of a pre-existing placeholder than when it appeared abruptly in a blank location around the color-patch target (Experiment 1). Furthermore, dilution of the Stroop effect in the presence of an additional, neutral word depended on which of the two words was presented more abruptly (Experiments 2 & 3), suggesting attentional competition between them. These results imply that the color word in the Stroop task is recognized when it captures attention.

Key words : Stroop effect, automatic process, visual attention, attentional capture, abrupt onset

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Well-practiced activities, such as riding a bicycle or typewriting, can be performed without much effort or conscious thought through a process of automatization (Logan, 1988). Due to the complex and multifaceted nature of the phenomenon, there is no single widely accepted definition of automaticity. In a traditional view, automatic processing is characterized as meeting three criteria (Posner & Snyder, 1975; Schneider & Shiffrin, 1977). Automatic processing is presumed to occur regardless of intention, uses only minimal attentional resources, and occurs outside of conscious awareness. However, a lack of co-occurrence among these features (e.g. Bargh, 1992; Kahneman & Treisman, 1984; Logan & Cowan, 1984; see Moors & De Houwer, 2006) makes it untenable to draw a clear line between automatic and non-automatic processes based on the presence or absence of the features. A recent analysis suggests that these features are, to a large extent, conceptually separable and thus should be investigated separately (Moors & De Houwer, 2006). According to this separable features view, a process can be considered automatic in terms of some features and non-automatic in terms of others. As a case in point, the Stroop color-naming effect is often taken as compelling evidence for the unintentional nature of word recognition (Stroop, 1935; see MacLeod, 1991, for a review), but it has been found to be dependent on attentional resources (Francolini & Egeth, 1980; Kahneman & Chajczyk, 1983; but see Brown, Gore, & Carr, 2002).

In the classic Stroop task, a colored color-word is presented and participants are to name the color of the target while ignoring the meaning of the color word. Color-naming responses are typically slower and more error-prone when the meaning of the color word and the target color are incongruent than when they are congruent (e.g., Oh & Chung, 1992). The Stroop effect reveals the *obligatory* nature of word recognition in that the word meaning influences the naming response even if participants do not intend to process the meaning (Stroop, 1935). The Stroop effect has been shown to occur when the color word is presented at a separate location from the target color (Brown, Roos-Gilbert, & Carr, 1995; Kahneman & Chajczyk, 1983) and after extended practice with the task (see MacLeod, 1991). The robustness of the Stroop effect has been taken to suggest that processing of the color word is largely *autonomous* in the sense that it cannot be stopped or altered once initiated (Brown, Gore, & Carr, 2002).

In contrast, automaticity of word recognition in terms of *attentional resource demands* was challenged by Kahneman and Chajczyk (1983). In their Experiment 1, a color bar was presented at the center as a target, with a color word appearing above or below the bar.

Critically, the color word was sometimes accompanied by an additional, color-neutral word on the other side of the bar. If capacity-free processing of words is assumed, then processing of the color word should be unaffected by the presence of the additional word in the display. However, the Stroop effect was substantially reduced in the presence of the neutral word, a phenomenon called the *Stroop dilution effect* (Yee & Hunt, 1991). Kahneman and Chajczyk took this finding to suggest that reading of color words occurs serially, requiring at least some amount of attention. When a single color word is presented with a bar, the color word always attracts attention, affecting color-naming responses on all trials. When a color word and a neutral word are simultaneously presented, the color word's impact depends on which word receives attention: The processing of the color word will be normal if the color word captures attention but disrupted if the neutral word captures attention. Assuming that two words have equal chances of capturing attention, the Stroop effect should be reduced by about half when a neutral word is presented compared to when no neutral word is presented, as Kahneman and Chajczyk found.

Although the demonstration of the Stroop dilution effect suggests that the processes underlying the Stroop effect are dependent on some limited resources, it remains unclear whether the processing limit arises at the stage of word recognition or not. This issue has been addressed more directly in recent studies in which the allocation of visual attention was manipulated by means of spatial precuing. For example, in Brown et al.'s (2002) study, uninformative, abrupt-onset cues were used to summon attention to the location at which a color-bar target, a color word, or a neutral word would appear. In a one-word display, the size of the Stroop effect was smaller when the color bar was cued compared to when the color word was cued. Cuing the color word in a two-word display prevented dilution of the Stroop effect, but cuing the neutral word did not eliminate the Stroop effect. Based on the occurrence of a reliable Stroop effect even when attention was focused on the neutral word, Brown et al. claimed that word recognition is not only involuntary but also unlimited in capacity. According to them, the Stroop dilution effect does not reflect a bottleneck in the word recognition system but is due to degradation of the early feature representation of the color word (Brown et al. 1995). Visual encoding of the color word is degraded by the neutral word because early feature representations of the words suffer mutual interference through a process called visual-crosstalk. The low quality visual data available to the word recognition system in turn results in reduced lexical or semantic activation of the color word. From this view, focused visual attention is a modulator that protects visual data from crosstalk-based interference, but it is not a necessary condition for word recognition to occur.

Choi, Cho, and Proctor (2009) made another attempt to control the focus of visual attention with exogenous cues, but they went a step further by taking into account both facilitatory and inhibitory effects of exogenous cuing. Using manual responses, Choi et al. tested whether the Stroop effect is modulated by inhibition of return (IOR; Posner & Cohen, 1984) by manipulating the stimulus onset asynchrony (SOA) between the cue and target displays. In Experiment 1, a cue briefly appeared above or below the central fixation. A color bar and a color word were presented, one at the cued location and one at the uncued location after an SOA of 100 or 1,050 ms. In Experiment 2, the color bar was always presented at a central location, with the color word appearing at a cued or uncued location above or below the color bar. Attention was supposedly directed to the cued location at a 100-ms SOA but directed away from the cued location at a 1,050-ms SOA. In both experiments, the color word produced a larger Stroop effect when presented at the cued location than at the uncued location at 100-ms SOA, but a smaller Stroop effect was obtained at the cued than at the uncued location at a 1,050-msec SOA. Thus, the impact of the color word was impaired when the color word appeared outside the focus of visual attention. Although directing attention away from the color word did not completely eliminate the Stroop effect, the results provide additional evidence that the processing of the color word is substantially modulated by whether attention is directed to the color word or not.

Together, these studies are consistent in showing that the size of the Stroop effect is dependent on attentional resources allocated to the color word, but the question still remains as to whether attention is required for color-word processing or not. On the one hand, Brown et al. (2002) interpreted the smaller but reliable Stroop effect occurring at the uncued location as evidence that word recognition can occur outside the focus of attention. On the other hand, there are reasons to suspect that attention still played a role in processing of the color word appearing at the uncued location. The color words were presented with abrupt onsets, which have been found to be particularly powerful in capturing attention (Jonides & Yantis, 1988; Yantis & Jonides, 1984). Moreover, although spatial cuing is typically used to direct attention to a specific location, it does not preclude a shift of attention to the uncued location. According to previous research, an attentional shift toward an irrelevant object having an abrupt onset can occur within

100 ms of its appearance (Lachter, Forster, & Ruthruff, 2004). Given the abrupt onset of the color word, it is possible that, after attention was initially captured by the exogenous cue, the color word could attract attention toward itself before the display terminated. The attention-capturing effect of the abrupt onset of the color word has been largely overlooked in prior research despite its relevance to the issue of the role of attention in word recognition. To the extent that the size of the Stroop effect is dependent on the bottom-up saliency of the color word, visual attention would be considered a necessary condition for word recognition to occur. Such saliency may also shed light on why it is difficult to prevent the Stroop effect under so many experimental conditions.

The aim of the present study is to investigate the role of visual attention in processing of the color word in the Stroop task. Unlike previous studies that used exogenous spatial cues to control the allocation of attention, the present study attempted to manipulate the attention-capturing ability (or abruptness of onset, as operationally defined in this study) of the color word per se. As discussed earlier, the issue of intentionality can be disentangled from that of capacity demands. The fact that word recognition occurs unintentionally does not necessarily indicate capacity-free processing, nor does it preclude control by attention. Rather, unintentional recognition may reflect salient visual properties (i.e. abrupt onsets), drawing attention to the word involuntarily. If involuntary attentional orienting to the color word at its onset is responsible for triggering lexical activation of the word, the Stroop effect should be modulated by the attention-capturing ability of the color word. Regardless of whether the color word is presented as the only distractor or is accompanied by another word, the size of the Stroop effect should be a function of the attentional priority given to the color word, as determined by the relative saliency of the stimuli (see Koch & Ullman, 1985). Alternatively, if it is the presence of linguistic input that automatically triggers word recognition, the Stroop effect should be of constant size as long as the visibility of the color word remains unchanged.

Manual responding, which was used in Choi et al.'s (2009) study, has been criticized as being a less sensitive measure of the processes that give rise to Stroop interference than is vocal responding (Sharma & McKenna, 1998). Whereas vocal responses can be directly influenced by the word's access to the lexical system (Glaser & Glaser, 1989; Virzi & Egeth, 1985), it may not be the case for manual responses, which do not necessarily rely on verbal representations. Hence, the attentional modulation of the color word's impact as measured by manual reaction time (RT) may not be a sensitive measure of the modulation of the lexical activation. This concern was eliminated in the present study by using vocal responses.

Experiment 1

The aim of Experiment 1 was to examine whether the Stroop effect is modulated by stimulus-driven attentional capture by the color word. The allocation of attention was varied by presenting the color word as an abrupt onset or a non-abrupt onset. Panticipants were told to name the color of a target presented at fixation while ignoring a color word presented at one of six peripheral locations of a circular array. Before onset of the target and color word, three of the peripheral locations were occupied by placeholders. The color word either appeared at one of the three blank locations between the placeholders (abrupt onset) or inside one of the placeholders (non-abrupt onset). An empty box was used as a placeholder to prevent visual masking of the color word occurring inside it. Although this type of placeholder may not be as effective as the figure-eight placeholders used by Todd and Van Gelder (1979) and Yantis and Jonides (1984), our primary concern was to minimize the perceptual quality difference of the color word between when the color word was presented as an abrupt onset and when it was presented as a non-abrupt onset.

The color word with an abrupt onset should be more likely to attract attention than the color word with a non-abrupt onset. Thus, if color word recognition requires visual attention, the Stroop effect should be more evident when the color word is presented as an abrupt onset than when it is not. On the other hand, if the meaning of the color word is automatically accessed, the impact of the color-word meaning should be constant regardless of whether the color word has an abrupt onset or not.

Method

Participants Twenty undergraduate students at Korea University participated to fulfill a partial course requirement. All were fluent Korean speakers and had normal or corrected-to-normal visual acuity and color vision as determined by self-report.

Stimuli and Apparatus E-prime software (Version 1.2, Psychology Software Tools, Pittsburgh,PA) was used to control the experiment. Stimuli were displayed on a 17-in. CRT monitor of a personal computer at a viewing distance of approximately 60 cm. Color names were spoken into a microphone interfaced with a Serial Response Box (Psychology Software Tools, Pittsburgh, PA). The microphone was

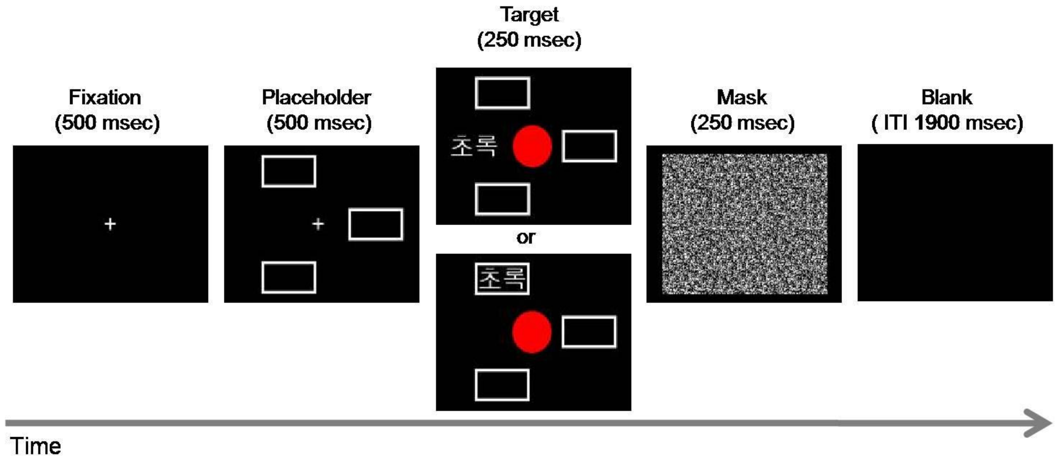

Figure 1. Trial sequence for Experiment 1. In the target display, a color word was presented as an abrupt onset (upper one) or as a non-abrupt onset (lower one) as a distractor. Only one of the two possible types of placeholder display is depicted.

placed at the participant's sagittal midline. The identity of the vocal response was entered by an experimenter via a keyboard.

All stimuli were presented against a black background. The target stimulus was a circle (2.10° diameter) colored in blue [RGB: 0, 0, 255], green [RGB: 0, 168, 20], red [RGB: 255, 0, 0], or yellow [RGB: 0, 255, 255], presented at the center of the screen. Korean words for 'blue', 'green', 'red', and 'yellow' were used as distractors: "빨강" [pal-ghang], "노랑" [no-rang], "초록" [cho-rok], and "파랑" [pah-rang], respectively, which were presented in white (1.05° x 2.20°). The placeholder was a white outline rectangle (1.53° x 2.77°), slightly larger than the color word, with a line width of 0.14°. Placeholders appeared at three of six possible stimulus locations, which were positioned on an imaginary circle with a radius of 2.77° that was centered on the screen. The three locations were selected on each trial such that the placeholders appeared at every other location (see Figure 1). This resulted in two different placeholder layouts, which varied randomly from trial to trial. The distance between the centers of any two placeholders was 4.95°.

Procedures Participants were tested individually in a dark room. They were instructed to name the color of the circle presented at the center of the screen as quickly and accurately as possible, and to ignore the other stimuli on the display.

At the beginning of each trial, a white cross (0.57° x 0.57°), on which participants were asked to fixate, was presented at the center of the screen. After 500 ms, three placeholders were presented around the fixation cross for 500 ms. Then, a target display containing a colored circle and a color word was presented for 250 ms. The color word appeared in one of the three placeholders (non-abrupt onset) on half of the trials, and in one of the three blank locations (abrupt onset) on the other half. On half of each of the non-abrupt onset and abrupt onset trials, the target color and the meaning of the color word were congruent, and on the other half, they were incongruent. At stimulus offset, a pattern mask (a rectangle of 7.59° x 9.83° covering an area slightly larger than the stimulus field of the target display) was presented for 250 ms. Participants' vocal RT was measured. Immediately following the participant's vocal response, the experimenter entered its identity into a computer file by pressing a corresponding key (red, yellow, green, or blue). In case of an incorrect response, auditory feedback was given for 150 ms through small speakers placed to the left and right sides of the monitor. The next trial began after an intertrial interval of approximately 1,900 ms, during which the screen remained blank.

The experiment began with a 24-trial practice block followed by a 160-trial experimental block. The experimental block contained 40 trials for each combination of color-word onset type (abrupt and non-abrupt onset) and congruency (congruent and incongruent). The four conditions were randomly mixed. Separate stimulus lists were constructed for these conditions, using all possible combinations of target color, color word, placeholder layout, and color word location. The stimuli were randomly selected on each trial from the respective stimulus list, with the constraint that each target color was used equally often in each condition. Consequently, for incongruent trials, some color/word pairs were presented more often than other pairs.

Results

RTs shorter than 150 ms or longer than 1,500 ms (a total of 0.22%) were removed from analysis as outliers. Mean RT and percentage error (PE) were calculated for each participant as a function of color-word onset type (abrupt onset or non-abrupt onset) and congruency (congruent or incongruent color word). Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with those variables as within-subject factors (see Table 1).

RT The main effect of congruency was significant, $F(1, 19) = 188.93$, $p < .001$, $MSe = 476$. A 67-ms Stroop effect was obtained. The main effect of color-word onset type was not significant, $F\ (1, 19) = 1.92$, $p = .181$, $MSe = 170$, but the interaction of congruency with

Table 1. Mean Reaction Time(RT; in Milliseconds) and Percentage of Error(PE; in Parentheses) in Experiment 1 as a Function of Color-Word Onset Type and Congruency

Color-Word Onset Type	Congruency					
	Congruent		Incongruent		Stroop Effect	
Non-abrupt Onset	507	(0.25)	565	(2.64)	58	(2.39)
Abrupt Onset	502	(0.75)	578	(2.76)	76	(2.00)

color-word onset type was significant, $F(1,19) = 5.81$, $p = .026$, $MSe = 252$. The Stroop effect was greater when the color word was presented as an abrupt onset (76 ms) than as a non-abrupt onset (58 ms, being significant for both conditions, $Fs\ (1, 19) = 227$ and 136, $ps < .001$, $MSe = 252$.

PE Overall PE was 1.60%. There was a significant effect of congruency, $F(1,19) = 26.88$, $p < .0001$, $MSe = 3.59$. The main effect of color-word onset type was not significant, $F(1,19) = 0.83$, $p = .373$, $MSe = 2.30$, nor was its interaction with congruency, $F(1,19) = 0.18$, $p = .672$, $MSe = 4.07$.

Discussion

The Stroop effect was modulated by the onset type of the color word. The Stroop effect was 76 ms when the color word was presented as an abrupt onset but only 58-ms Stroop effect when the color word was presented as a non-abrupt onset. The reduction of the Stroop effect with non-abrupt onset is considered to be due to the failure of the color word to attract attention when it was presented as part of an already-present object, rather than as a suddenly appearing new object. This suggests that the color-word processing was dependent on the likelihood of a shift of attention to the color word.

Nevertheless, there is a possibility that presenting the color word inside the placeholder degraded the visual quality of the word, causing it to be encoded less efficiently than the word presented at a blank location (see Gibson, 1996). That is, the reduced Stroop effect obtained with the color word inside the placeholder could be due to the reduced perceptual input to the word-recognition system. Experiment 2 was conducted to determine whether the modulation of the Stroop effect obtained in Experiment 1 was caused by a change in readability of the color word or in likelihood of attentional capture by the color word.

Experiment 2

To test whether presenting the word as a non-abrupt onset reduces the occurrence of an attention shift to the color word or degrades the visual quality of the word, an additional neutral word was introduced to the displays used in Experiment 1. A target and a color word were presented, with a neutral word appearing inside one of the placeholders as a non-abrupt onset on half of the trials, and without a neutral word on the other half. Cho et al. (2006) assumed that, when a neutral word is introduced in the Stroop display, competition for attention occurs between the two words, with the meaning of the color word having an impact only when the color word captures attention. Thus, if the word presented as an abrupt onset is more powerful in capturing attention than is the word presented as a non-abrupt onset, presenting the neutral word as a non-abrupt onset should have little influence on the magnitude of the Stroop effect when the color word is presented as an abrupt onset. On the other hand, the neutral word should reduce the impact of the color word presented as a non-abrupt onset since the two words would be equally competitive in capturing attention. Alternatively, if the word presented as a non-abrupt onset is less likely to be recognized due to a reduced readability, the Stroop dilution effect should occur regardless of whether the color word is presented as an abrupt onset or not.

Method

Twenty new undergraduate students from the same participant pool as in Experiment 1 participated. The apparatus, stimuli, and procedures were identical to those in Experiment 1, with the following exceptions. Four Korean words that had no association with any color meaning were used as neutral words: 중심 (center), 전기 (electricity), 함성 (shout), and 향수 (perfume). These words have the same number of syllables and a similar frequency in the language as the color words.

The color-word onset type and congruency manipulations used in Experiment 1 were crossed with the presence of a neutral word, resulting in eight experimental conditions. A color word appeared in one of three placeholders (non-abrupt onset) on half of the trials, and in one of the other three possible locations (abrupt onset) on the other half. For each color-word onset type, the meaning of the color word was congruent with the target color on half of the trials and incongruent on the other half. Critically, on half of each of these trial types, a neutral word was presented in one of the placeholders as an additional distractor. On the other half, no neutral word was presented.

Each participant received a 24-trial practice block and two 160-trial experimental blocks. A 1-min rest period was given between the experimental blocks. In each experimental block, there were 20 trials for each combination of color-word onset type (abrupt and non-abrupt onset), congruency (congruent and incongruent), and neutral word (present and absent). The eight conditions were randomly mixed. The stimuli for each of these conditions were randomly selected (without replacement) from the respective stimulus list, with the constraint that each of the four target colors was equally represented within each condition. The neutral word (and its location), when present, was randomly selected on each trial, resulting in an approximately equal number of each of the four neutral words in each condition.

Results

0.69% of the trials were removed from analysis using the same criteria as those in Experiment 1. Mean correct RT and PE were calculated for each participant as a function of color-word onset type (abrupt onset or non-abrupt onset), congruency (congruent or incongruent color word), and neutral word (no neutral word or neutral word). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors. Mean RTs and PEs are shown in Table 2.

RT A significant main effect of congruency was obtained, $F(1, 19) = 128.92$, $p < .001$, $MSe = 1{,}044$, reflecting a 59-ms Stroop effect. As in Experiment 1, the interaction of congruency with color-word onset type was significant, $F(1, 19) = 128.92$, $p = .029$, $MSe = 351$. The Stroop effect was larger when the color word was presented as an abrupt onset (65 ms) than as a non-abrupt onset (51 ms). The main effect of color-word onset type reached significance, $F(1, 19) = 10.23$, $p = .005$, $MSe = 160$. Mean RT was faster when the color word was presented as a non-abrupt onset (547 ms) than when it was presented as an abrupt onset (553 ms). The main effect of neutral word was not significant, $F(1, 19) = 0.99$, $p = .333$, $MSe = 246$.

The presentation of a neutral word caused a significant Stroop dilution effect, as reflected in a significant interaction of congruency with neutral word, $F(1, 19) = 5.14$, $p = .035$, $MSe = 232$. Although the three-way interaction of color-word onset type, congruency, and neutral word did not reach significance, $F(1, 19) = 2.04$, $p = .170$, $MSe = 284$, separate analyses showed that a significant dilution effect was obtained when the color word was presented as a non-abrupt onset (19 ms; 30.7%), $F(1, 19) = 5.16$, $p =$

Table 2. Mean Reaction Time(RT; in Milliseconds) and Percentage of Error(PE; in Parentheses) in Experiment 2 as a Function of Color-Word Onset Type, Congruency, and Neutral Word

Color-Word Onset Type and Neutral Word	Congruency				Stroop Effect	
	Congruent		Incongruent			
Non-abrupt Onset						
No Neutral Word	511	(0.25)	572	(1.02)	60	(0.77)
Neutral Word	518	(0.50)	559	(1.39)	42	(0.89)
Abrupt Onset						
No Neutral Word	514	(0.75)	581	(2.77)	67	(2.02)
Neutral Word	514	(0.38)	577	(1.75)	63	(1.38)

.035, MSe = 333, but not when it was presented at as an abrupt onset (3 ms; 5.0%), $F(1, 19) < 1.0$, $p = .590$, MSe = 183. Further analyses of simple main effects revealed that the Stroop effect was significant in all four conditions. In non-abrupt onset conditions, a 60-ms Stroop effect, $F(1, 19) = 128.02$, $p < .001$, MSe = 284, was obtained without a neutral word and a 42-ms Stroop effect, $F(1, 19) = 61.40$, $p < .001$, MSe = 284, with a neutral word. In abrupt onset conditions, a 67-ms Stroop effect, $F(1, 19) = 156.41$, $p < .001$, MSe = 284, was obtained without a neutral word and a 63-ms Stroop effect, $F(1, 19) = 141.21$, $p < .001$, MSe = 284, with a neutral word.

PE Overall PE was 1.10%. There was a main effect of congruency, $F(1, 19) = 17.81$, $p < .001$, MSe = 3.60, indicating a 1.27%-Stroop effect. The main effect of color-word onset type approached the .05 level, $F(1, 19) = 4.31$, $p = .052$, MSe = 3.58, with error rates tending to be lower when the color word was presented as a non-abrupt onset (0.79%) rather than an abrupt onset (1.41%). The interaction of color-word onset type and neutral word was significant, $F(1, 19) = 4.92$, $p = .039$, MSe = 2.05. When the color word was presented as an abrupt onset, PE was higher without a neutral word (1.76%) than with a neutral word (1.06%), $F(1, 19) = 4.71$, $p = .043$, MSe = 2.05. However, when the color word was presented as a non-abrupt onset, there was no such effect, $F(1, 19) < 1.0$. No other terms were significant, $Fs < 2.13$.

Discussion

As in Experiment 1, the size of the Stroop effect was modulated by the onset type of the color-word. When the color word alone was presented with the target, the Stroop effect tended to be larger for the color word presented as an abrupt onset (67 ms) than the color word presented as a non-abrupt onset (60 ms). This modulation effect (6 ms) was not as pronounced as that obtained in Experiment 1 (17 ms), which may be due to changes in the task set brought about by intermixing two different display types. It is possible that participants implicitly adjusted their attentional sets depending on the types of displays they encountered throughout the experimental blocks. Compared to Experiment 1, in which participants were only presented with only one-word displays, the dynamic switching between one-word and two-word displays in the present experiment could make the task more demanding, which would delay an attentional shift to the abruptly appearing color word, which would otherwise have captured attention more effectively. This result, however, does not necessarily imply a loss of "attentional priority tags" (Yantis & Johnson, 1990) or saliency values (Koch & Ullman, 1985) assigned to the abrupt onsets. As discussed below, the results from the two-word displays clearly indicate processing priority of abrupt onset stimuli over non-abrupt onset stimuli.

Most important, when a neutral word was additionally presented in a non-abrupt onset fashion, its impact on the magnitude of the Stroop effect depended on the onset type of the color word. The Stroop effect decreased from 60 ms to 42 ms when the color word was presented as a non-abrupt onset, a dilution effect of 31%. By contrast, when the color word was presented as an abrupt onset, the 67-ms Stroop effect decreased to 63 ms, resulting in a non-significant dilution of only 5%. This result is inconsistent with the readability account, which predicts a similar amount of dilution effect regardless of the color-word location. The absence of a Stroop dilution effect when the color word appeared at a previously empty location indicates that the color word received processing priority over the neutral word presented at the placeholder. On the other hand, the occurrence of a Stroop dilution effect when both words were presented at placeholders suggests that, in that case, there was no such processing priority among the two words. Apparently, the preexistence of the placeholder reduces the likelihood of attentional capture by the word appearing at that location, rather than interrupting the early visual processing of the word. Therefore, the modulation of the Stroop effect observed in Experiment 1 can be viewed as resulting from the difference in the likelihood of an attention shift to the color word appearing at the placeholder and blank locations.

The abrupt onset of the color word caused a small but significant delay (6 ms) in the overall color-naming RTs compared to when it was presented without an abrupt onset. This might be due, in part, to a cost of filtering out the irrelevant stimulus (Kahneman, Treisman, & Burkell, 1983), especially when the distractor word is salient enough to compete for attention. An additional presentation of a neutral word, on the other hand, produced no such delay in RTs, perhaps because, in the present experiment, the neutral word was always presented as a non-abrupt onset. Alternatively, the increased RTs in the abrupt-onset conditions may simply reflect the larger Stroop effects obtained in these conditions. In the case that the interference component of the Stroop effect is greater than that of facilitation, longer RTs can be reliably associated with larger Stroop effects.

Experiment 3

In the previous two experiments, the likelihood of attentional capture by the color word was manipulated by varying the onset type of the color word. The Stroop effect was larger for the color word with an abrupt onset than for the color-word with a non-abrupt onset (Experiment 1), and the introduction of a neutral word with a non-abrupt onset produced a significant Stroop dilution effect only when the color word was also a non-abrupt onset stimulus (Experiment 2). Conversely, assuming attentional competition between the color word and the neutral word, the occurrence of an attention shift to the color word would be also dependent on the neutral word's ability to capture visual attention. Therefore, in Experiment 3, the likelihood of attentional capture by the color word was manipulated by varying the onset type of the neutral word. As in Experiment 2, the target was accompanied by two distractors, a color word and a neutral word. However, the color word was always presented with a non-abrupt onset while the neutral word was presented with an abrupt onset or a non-abrupt onset. Because an abrupt onset stimulus receives higher priority over a non-abrupt onset stimulus, attention should be less likely to be captured by the color word when the neutral word is presented with an abrupt onset than when the neutral word is presented with a non-abrupt onset. Thus, if color-word recognition in the Stroop task depends on visual attention, the Stroop effect should be less evident when the neutral word has an abrupt onset than when it has a non-abrupt onset.

One possible problem with the use of an empty box as a placeholder in Experiments 1 and 2 is that the stimulus presented inside the box could still be experienced as a sudden appearance of a new object rather than a change

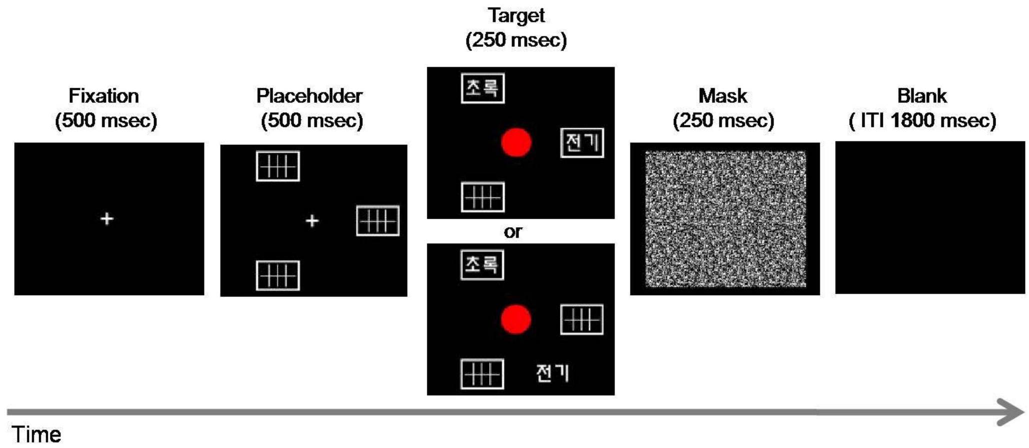

Figure 2. Example stimuli used in Experiment 3. In the target display, a neutral word was presented as a non-abrupt onset (upper one) or an abrupt onset (lower one) while a color word was always presented as a non-abrupt onset.

in an existing object. In the present experiment, therefore, the placeholder display was modified such that each placeholder was filled with a horizontal line crossed by three short vertical lines (see Figure 2). This modification was made to maximize the difference in the abruptness between the word appearing inside the placeholder and the word appearing at a blank location. Since the physical properties of the color word per se was kept constant (i.e., it was always presented inside the placeholder) regardless of the onset type of the neutral word, the possible masking effects by the placeholder would not account for the modulation of the Stroop effect.

Method

Twenty new undergraduate students at Korea University were recruited and paid for their participation. The apparatus, stimuli, and procedures were identical to the previous experiments, with the following exceptions. The size of the stimuli was adjusted in order to reduce the variations in the spacing between items occurring at different locations. The size of the word stimuli was reduced by 17% in height, and 38 % in width, resulting in 0.9° and 1.4° in width and height. The size of the placeholder box was also reduced by 12% in height, and 32% in width (1.3° x 1.9°). The target size was 2.10° in diameter, which was a 32% reduction. However, the center-to-center distances between the items were remained unchanged.

The target display consisted of a colored circle at the center and two distractors, a color word and a neutral word, at peripheral locations. The color word was always presented at one of the three placeholders, as a non-abrupt onset, replacing the pre-mask within the placeholder. The meaning of the color word was congruent with the target color on half of the trials and incongruent on the other half. On half of each of the congruent and incongruent trials, a neutral word was presented in one of the remaining placeholders, also as a non-abrupt onset. On the other half of the congruent and incongruent trials, the neutral word was presented at one of the three blank locations, as an abrupt onset. The ITI was fixed at 1,800 ms, by allowing a one-second time window for the experimenter to categorize the vocal response.

Each participant performed a 24-trial practice block and a 192-trial experimental block. The experimental block contained 48 trials for each combination of neutral-word onset type (abrupt and non-abrupt) and congruency (congruent and incongruent). All conditions were randomly mixed, and the stimuli were randomly selected on each trial from the respective stimulus set, with the constraint that each target color was used equally often in each condition. In the preceding experiments, the location of the color word was randomly selected among six possible locations, resulting sometimes in an unequal spatial distribution of the color word across conditions. To reduce the variability in the magnitude of the Stroop effect caused by the stimulus location, the present experiment controlled the location of the color word more precisely. Thus, each experimental condition contained 12 trials for each target color, 2 for each color-word location.

Results

A total of 0.73% of the trials was removed from the analysis using the same criteria as in Experiments 1 and 2. Mean correct RT and PE were calculated for each participant as a function of neutral-word onset type (abrupt or non-abrupt onset), and congruency (congruent or incongruent color word). ANOVAs were conducted on the mean RT and PE data, with those variables as within-subject factors. Mean RTs and PEs are shown in Table 3.

RT The main effect of congruency was significant, $F(1, 19) = 53.63$, $p < .001$, $MSe = 602$, reflecting a 40-ms Stroop effect. The main effect of neutral-word onset type was not significant, $F(1, 19) = 1.23$, $p = .281$, $MSe = 179$, but there was a significant interaction effect of congruency and neutral-word onset type, $F(1, 19) = 8.45$, $p = .009$, $MSe = 112$.

Table 3. Mean Reaction Time(RT; in Milliseconds) and Percentage of Error(PE; in Parentheses) in Experiment 3 as a Function of Neutral-Word Onset Type and Congruency

Neutral-Word Onset Type	Congruency					
	Congruent		Incongruent		Stroop Effect	
Non-abrupt Onset	502	(0.53)	549	(3.46)	47	(2.93)
Abrupt Onset	512	(0.42)	545	(2.22)	33	(1.80)

When the neutral word was presented as a non-abrupt onset, a 47-ms Stroop effect was obtained, $F(1, 19) = 198.26$, $p < .001$, $MSe = 112$, but when it was presented as an abrupt onset, only a 33-ms Stroop effect was obtained, $F(1, 19) = 99.41$, $p < .001$, $MSe = 112$.

PE The overall PE was 1.66%. There were significant main effects of congruency, $F(1, 19) = 17.72$, $p < .001$, $MSe = 6.31$, and neutral-word onset type, $F(1, 19) = 4.85$, $p = .040$, $MSe = 1.91$. A 2.37-% Stroop effect occurred. PE was higher when the neutral word was presented as a non-abrupt onset (2.00%) than as an abrupt onset (1.32%). Although the interaction of congruency and neutral-word onset type did not reach significance, $F(1, 19) = 2.92$, $p = .104$, $MSe = 2.20$, there was still a tendency toward a smaller Stroop effect in the non-abrupt onset condition.

Discussion

The size of the Stroop effect was modulated by whether the neutral word was presented as an abrupt onset or not. When the neutral word was, along with the color word, a non-abrupt onset stimulus, a 47-ms Stroop effect occurred, a value comparable to that obtained under the same condition in Experiment 2 (42 ms). However, when the color word was accompanied by a neutral word having an abrupt onset, only a 33-ms Stroop effect was found. This result suggests that, even when the physical stimulus properties of the color word remained identical, the meaning of the color word was less likely to influence the color-naming response as attention was more likely to be directed to the neutral word than to the color word. Although the attentional capture by the abrupt onset neutral word did not completely eliminate the Stroop effect, the result does show that, on a portion of trials, the color word was recognized when it captured attention.

General Discussion The present study tested the hypothesis that visual attention modulates recognition of the color word in the

Stroop task. In Experiment 1, the Stroop effect was larger when the color word was presented with an abrupt onset than when the color word was presented with a non-abrupt onset. This modulation of the Stroop effect was attributed to attentional factors, rather than to the visual quality difference between the abrupt- and non-abrupt onset stimuli, based on the following results. In Experiment 2, presenting a neutral word with a non-abrupt onset significantly reduced the size of the Stroop effect when the color word was also presented with a non-abrupt onset, but not when the color word was presented with an abrupt onset. In Experiment 3, in which a color word with a non-abrupt onset was accompanied by a neutral word with a varying onset type, a significantly smaller Stroop effect was obtained when the neutral word had an abrupt onset than when it had a non-abrupt onset.

The Stroop dilution effect has been interpreted as reflecting the capacity limitations in visual word recognition (Kahneman & Chajczyk, 1983). An alternative view, however, is that the crosstalk among multiple patterned stimuli reduces the input to the word recognition system, which is of unlimited capacity (Brown et al. 1995). According to Brown et al., what ultimately controls the degree of the color word's lexical activation is the quality of its early feature representations, which is determined by "the number of additional distractors in the display and their featural complexity" (p. 1407). Because these factors were held constant in the present study (i.e., a single neutral word was additionally presented, using the same set of stimuli), the amount of the crosstalk that a color word would receive should be same in any dilution condition. However, instead of causing a similar amount of dilution, the influence of the neutral word on the processing of the color word varied depending on the onset type of either word. These results cast doubt on the view that processing of the color word is degraded at early visual encoding stages. Instead, attentional selection of either word at the stage of recognition appears to be a more plausible explanation for the observed modulation of the Stroop dilution.

The present findings also shed light on the factors that contribute to the involuntary reading of the color word in the Stroop task. The processing of the color word in this study was modulated by the way the stimuli were presented - the onset type of the color word, as well as that of the neutral word - while the physical stimuli presented were constant. This indicates that the abrupt onset of the word, rather than the presence of the word per se, is responsible for triggering the word reading. Hence, the involuntary aspect of word reading could be viewed as dependent on operation of a more general attention mechanism, in which stimuli with salient visual properties attract attention in a bottom-up fashion.

Although the present results indicate that the bottom-up allocation of attention to the color word accounts for a substantial portion of the Stroop effect, the exact nature of the attentional modulation is still debatable. Attention may have enabled word recognition directly by triggering the recognition process or, indirectly by preserving the quality of visual data during early visual encoding stages, as suggested by Brown et al. (2002). In fact, the observed modulation of the dilution effect may well be accommodated by the crosstalk account by assuming that the more likely the color word is to capture attention, the less the degradation of its visual encoding. Although the results from the two-word displays are ambiguous as to whether the selection took place at the recognition stage, the influence of attention in one-word displays may elucidate the exact role of attention in word recognition.

In Brown et al.'s (2002) framework, attention plays a subsidiary role in word recognition in that it functions to protect the attended word from crosstalk. This implies that attention comes into play when the visual encoding of the word is degraded by crosstalk, whereas its role is minimal without such crosstalk. Given that the crosstalk arises from the presence of "other complex patterns in the visual field" (p. 230), the degradation is unlikely to occur in a one-word display, where the color word is the only patterned stimulus presented. Hence, as far as the quality of visual data reaching a sufficient level, recognition of the color word would be achieved equally well, whether it is attended or not. In this regard, it is worth noting that the Stroop effect in one-word displays shows attentional modulation. In fact, attentional modulation of the basic Stroop effect was consistently observed in Brown et al.'s own study. On a display containing a color-bar target and a single color word, the Stroop effect was significantly smaller when an abrupt onset cue called the focus of attention to the color bar rather than the color word. The authors make a valid point in arguing that the persistence of the Stroop effect even when the focus of attention was drawn to the color bar is indicative of automatic processing of the color word. However, the issue of how the focus of spatial attention modulates the processing of the color word in one-word displays still needs to be addressed.

Another line of research points to a more direct role of attention in mediating the word-recognition process. Cho, Lien, and Proctor (2006) found that the likelihood that attention shifts from the color target to the flanking color word significantly modulates the magnitude of the Stroop effect. In their study, the Stroop effect was not reduced by the presence of a neutral word when the color word carried the target color, whereas Stroop dilution did occur when the color word was presented separately from the color bar. They argued that attention is always captured by the color carrier, which contains task-relevant information. Thus, coloring the color word prevented the dilution effect by attracting attention to the color word on all trials. More important, they demonstrated that the Stroop effect obtained when a color word is presented alongside a color bar is the result of an attention shift to the color word after the initial attentional selection of the color carrier (see also, Suh & Cho, 2013). In their Experiment 5A, the size of the Stroop effect was reduced as the exposure duration decreased, which allowed less time for attention to shift from the color bar towards the color word. This reduction was not attributable to a lack of readability with the brief presentation time since there was no decrease in the Stroop effect with shorter display durations when the color word was presented as the color carrier. This indicates that the color word could be fully processed even at the shortest display duration as long as the color word was at the initial focus of attention.

Kim, Cho, Yamaguchi, and Proctor (2008) provided more direct evidence for the modulation of color word processing by the shift of attention over time. In their Experiment 3, a color bar was presented at fixation and, on some trials, a neutral word was presented in the periphery. Critically, the color bar was replaced by a colored color-word with a varying delay. They found that, as the change from the bar to the color word was delayed, the Stroop effect decreased whereas the Stroop dilution effect by the neutral word increased. Kim et al. suggested that if the color word appeared before an attention shift occurred, the meaning of the color word affected color-naming performance without suffering the dilution effect. If the color word appeared after attention had shifted to the neutral word, the color word could not influence the color-naming response. Without a neutral word in the periphery, however, attention remained at the initially attended location, leading to the processing of the color word to some degree even at the longest delay. Together with the findings of Cho et al. (2006), these results corroborate the view that word processing in the Stroop task is not triggered solely by the presence of a word in the display but depends on attention being directed to the word.

Automaticity of Word Recognition In defining and explaining automaticity, the notion of intentionality is often coupled with the requirement for attentional resources (Hasher &

Zacks, 1979; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Automaticity develops gradually with practice (Logan, 1985; MacLeod & Dunbar, 1988), such that, after extensive training, stimulus input is sufficient for a fair amount of activation to spread along the processing pathway even without the allocation of attentional resources (Cohen, Dunbar, & McClelland, 1990). At the same time, this process is unintentional since it would occur independently of intention, given sufficient bottom-up stimulation. Whereas such characteristics would certainly constitute a purely stimulus-driven process, these features - processing in the absence of attention and intention - do not necessarily co-occur and are separable on a conceptual level (see Moors & De Houwer, 2006). As discussed earlier, a process that occurs without intention is not necessarily independent of attention (e.g. Bargh, 1992; Logan, 1992; Treisman, Squire, & Green, 1974). Attention can be voluntarily directed to currently important sources of information, but it can also be involuntarily driven to task-irrelevant sources of information. Considering the existence of multiple distinct attentional processes operating at different temporal stages of processing (Johnston, McCann, & Remington, 1995), a failure of voluntary control over a process at a particular stage does not necessarily indicate that the process is insusceptible to any forms of attentional control on the course of processing.

In the Stroop task, the lexical processing of the color word is not under voluntary control, culminating in the activation of response codes. However, there is converging evidence that recognition is sensitive to the distribution of spatial attention. Compared to the traditional Stroop task, which requires that spatial attention be directed to the location of the color word, the Stroop effect is substantially reduced in the modified paradigm in which the color patch and word are presented as separate objects. Even such a display can entail involuntary attentional shifts among the Stroop items, allowing some attention to be directed to the color word, however briefly. Combined effects of top-down and bottom-up factors determine the likelihood that the color word is attended, modulating the magnitude of the Stroop effect. Thus, the putatively automatic word processing in the Stroop task is considered to be dependent on the allocation of attention of some sort.

The fact that even a highly-practiced process such as word recognition relies on attention seems to indicate that attentional requirement may not be a useful criterion for diagnosis of automaticity. Indeed, several authors have challenged the traditional view that automatic processes have no requirements for attention (e.g. Cohen, Dunbar, & McClelland, 1990; Kahneman & Treisman, 1984; Logan, 1992). Given the dissociation of intention and attention (i.e. both intentional and unintentional processes are dependent on attention), one might be tempted to suggest that the obligatory nature of word recognition should be discussed separately from the attentional requirement of the process. This, however, may not necessarily be so if automaticity could be defined in terms of "relative" independence of attentional resources. All processes may depend on attention, but in varying degrees. For highly-practiced skills, such as word recognition, even a small amount of attention is sufficient to trigger a ballistic processing, making it relatively hard to control once initiated (see Bargh, 1992; Logan, 1992). For less-practiced tasks, on the other hand, greater attentional resources need to be directed to the stimulus (or to the process) for the completion of the task, which might involve voluntary control of attention. For example, in the parallel distributed processing framework (Cohen et al., 1990), the amount of the stimulus-driven activation is determined by the strength of that pathway, which gradually increases with practice. Given the continuous nature of pathway strengthening, even highly practiced processes can be influenced by the allocation of attention to some extent.

An alternative approach to automaticity is to define it in terms of the underlying process, rather than in terms of the attentional requirement. In Logan's (1988, 1992) instance theory of automatization, automaticity is viewed as a postattentive, memory phenomenon. Whereas novice performance is based on algorithmic computation, automatic performance is based on single-step direct-access memory retrieval. Attending to a stimulus causes obligatory encoding of the stimulus into memory, as well as the obligatory retrieval of all the information associated with it. Automatic processes are dependent on attention, in that attention enhances encoding of the attended information, provides stronger retrieval cues, and therefore increases the likelihood of obligatory retrieval. In this view, automatization is intricately dependent on attention, rather than being characterized by the gradual withdrawal of attention. Although theorists may differ in their conceptualization of automaticity, future endeavors should focus on addressing the intricate relation between attention, intention, and automaticity.

Conclusion

The present results demonstrate that recognition of the color word in the Stroop task is modulated by orienting of spatial attention, not only when the color word is presented as a single distractor with the target, but also in the presence of another, neutral word distractor.

Processing of the color word benefited from having an abrupt onset, such that a larger Stroop effect was obtained with a color word presented more abruptly. Furthermore, the Stroop effect suffered no dilution effect when the color word was presented more abruptly than the neutral word, whereas the dilution effect increased when the neutral word's onset was more abrupt than that of the color word. The fact that the enhanced processing of the abrupt onset stimulus was achieved at the expense of the competing, non-abrupt onset stimulus provides evidence for attentional selection based on bottom-up salience. Taken together, the present results lend support to the idea that the involuntary processing of the color word in the Stroop task occurs when the color word captures attention.

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스트룹 과제에서 갑작스럽게 제시된 색단어의 주의 획득 효과

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스트룹 효과가 단어의 자동 재인의 증거로 알려져 왔으나, 색 단어의 효과가 주의에 의해 영향을 받는다는 몇몇 연구가 보고되었다. 본 연구는 스트룹 과제에서 비자발적인 단어처리에서 시각 주의의 역할을 연구하였다. 색단어가 주로 갑작스러운 제시와 같이 상향적으로 주의를 획득하는 능력에 의해 스트룹 효과의 크기가 달라지는지 알아보고자 3개의 실험을 수행하였다. 실험 1에서는 색단어가 이미 제시된 상자 내에 제시되었을 때 보다 갑작스럽게 제시된 상자에 제시되었을 때 스트룹 효과가 더 컸다. 또한 추가적으로 제시된 중립 단어의 제시로 나타나는 희석효과는 두 단어 중 어떤 단어가 더 갑작스럽게 제시되었느냐에 따라 달라졌다 (실험 2와 3). 이러한 결과는 스트룹 과제에서 색 단어가 주의를 획득한 경우에만 재인됨을 의미한다.

주제어 : 스트룹효과, 자동처리, 시각주의, 주의 획득, 갑작스런 제시