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The role of attentional slippage in Stroop dilution☆

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ABSTRACT

The present study examined the cognitive locus of Stroop dilution using a psychological refractory period (PRP) paradigm. Participants were asked to perform a tone discrimination task via a bimanual keypress response and a modified Stroop task via a vocal response serially as Task 1 and Task 2, respectively. In Task 2, a neutral word was added on half of the trials and no neutral word on the other half of the trials to observe the Stroop dilution effect. The amount of Stroop dilution, as well as the Stroop effect, was relatively constant across different stimulus-onset asynchronies (SOAs), which implies that Stroop dilution occurs due to the competition between a neutral word and a color word after a target color bar is selected to be processed further. These results indicate that focused attention plays an important role in the modulation of Stroop interference by the presence of a neutral word.

1. Introduction

Reading is typically considered to be an automatic cognitive process, especially for highly skilled readers. Many researchers regard the reading process as not only involuntary but also independent from attention (LaBerge & Samuels, 1974), even though there is still much debate about the automaticity of reading (Brown, Joneleit, Robinson, & Brown, 2002; Kahneman & Chajczyk, 1983; Logan, 1997). One strong piece of evidence for the idea that word recognition is automatic comes from performance in a Stroop task, in which color-naming performance is impaired when the color and the meaning of the color word do not match (incongruent) compared to when they do (congruent), although the meaning of the color words has to be ignored for successful task performance (Stroop, 1935). The difference in performance between congruent and incongruent trials is called the Stroop effect. It has been suggested that Stroop interference is due to the automatic recognition of color words, resulting in delayed color-naming performance when an incongruent color word is presented (Keele, 1972; LaBerge & Samuels, 1974; for reviews, see MacLeod, 1991).

However, Kahneman and Chajczyk (1983) suggested that the cause of the Stroop effect is not that of pure automatic word recognition. In their experiments, they found that the magnitude of the Stroop effect was reduced when a neutral word was presented with a target color bar and a distractor color word in a display compared to that of the effect when no neutral word was presented with them. If all words are automatically recognized, the Stroop effect should have been constant regardless of the presence of a neutral word. This reduced Stroop effect is called the Stroop dilution effect (Brown, Roos-Gilbert, & Carr, 1995; Cho, Lien, & Proctor, 2006; Kahneman & Chajczyk, 1983; Mitterer, La Heij, & Van der Heijden, 2003). According to Kahneman and Chajczyk, selection competition occurs between the color and neutral words when they are presented together so that the color word is not recognized once the neutral word captures attention, resulting in reduced Stroop interference.

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Since Kahneman and Chajczyk found the Stroop dilution effect, several accounts have been proposed to explain it. Some of them have attributed Stroop dilution to attentional competition between the color and neutral words, as Kahneman and Chajczyk claimed (Cho et al., 2006; Mitterer et al., 2003). For example, Cho et al. assumed that words are recognized only when they capture attention. When a neutral word is presented with a color carrier and a color word, the color carrier has attentional priority over the other visual items based on the outcome of preattentive processes because it has a target-defining feature and is the most salient visual item in a target display. Thus, in most cases, the color carrier captures attention. However, attentional competition occurs involuntarily between the color and neutral words after the color carrier has been selected for processing. Only when the color word captures attention, does its meaning affect color-naming performance. Thus, because the probability that the color word captures attention is lower when a neutral word is presented with the color carrier and color word than when no neutral word is presented with them, the Stroop dilution occurs.

Brown et al. (1995) proposed an alternative account known as the 'early visual interference account' to explain the Stroop dilution effect. They suggested that items presented in a display are processed up to a semantic level without the allocation of attention. However, feature representations of visual items interfere with each other at an early visual processing stage when multiple words are presented in a display, resulting in degraded inputs for the next lexical processing stage. When feature representations are degraded, the response activation from the lexical representation also decreases so that the effects of the meaning of the color word on the color-naming performance are diluted.

Although many accounts for the Stroop dilution effect have been proposed, the mechanism and cognitive locus of Stroop dilution has not yet been clarified. The critical difference in the cause of dilution between the two major approaches is that one approach has centered on the attentional competition between the color and neutral words at the focused attention stage after the target to process is selected based on its relevancy and saliency (Cho et al., 2006; Kahneman & Chajczyk, 1983) and the other has focused on the perceptual crosstalk among feature representations of the words at the preattentive processing stage before the target is selected to process (Brown et al., 1995).

In the present study, the dual-task paradigm was used to examine the cognitive locus of the Stroop dilution effect. The dual-task paradigm has been widely used to examine the automaticity of word reading (McCann, Remington, & Selst, 2000; Ruthruff, Allen, Lien, & Grabbe, 2008). In this paradigm, participants are instructed to perform two simple tasks. When the temporal interval between the onsets of target stimuli for the two tasks, which is a stimulus onset asynchrony (SOA), is manipulated, the mean response time (RT) for the second task (T2) is found to be longer at short SOAs than at long SOAs. This delayed RT at short SOAs is called the psychological refractory period (PRP) effect.

The central bottleneck model has been suggested as a valid explanation for the PRP effect (Fig. 1). According to the model, information processing for both tasks can occur simultaneously at the perceptual processing stage. However, at a central bottleneck stage after the perceptual stage, only one task can be processed at a time. Therefore, information processing at the central stage for T2 has to be delayed until information processing at the central stage for the first task (T1) completes. At short SOAs, the processing of information for T2 after the perceptual processing stage should wait until response selection in T1 is completed. This pause of processing is

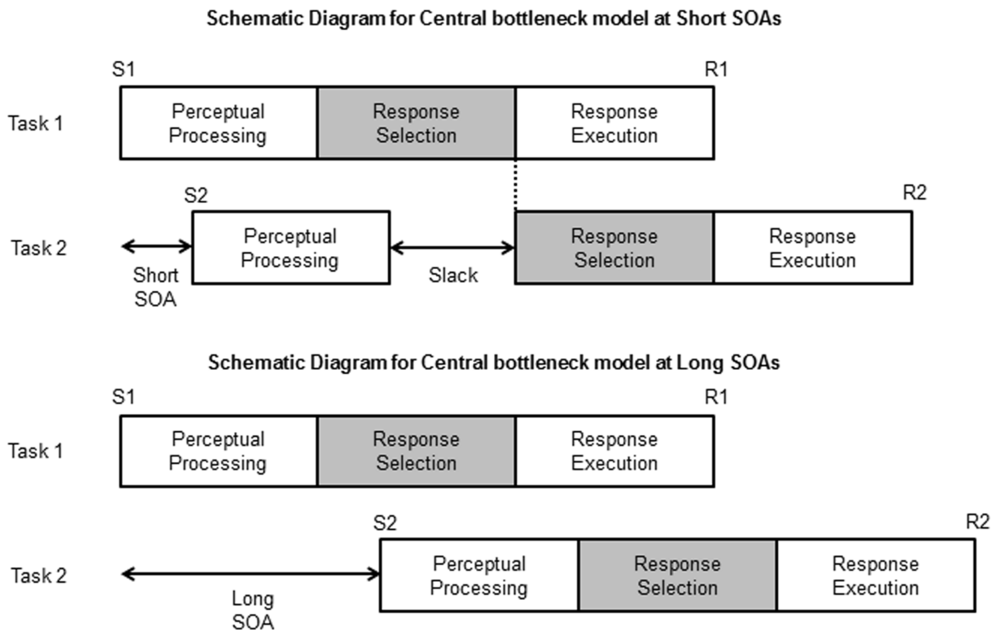

Fig. 1. The central bottleneck model in the psychological refractory period (PRP) paradigm. The central bottleneck stage of Task 2 does not start until the central processing of Task 1 finished, resulting in cognitive slack at short SOA. S1 = stimulus for Task 1; S2 = stimulus for Task 2; R1 = response for Task 1; R2 = response for Task2; SOA = stimulus onset asynchrony.

called "cognitive slack" (Schweickert, 1983). The amount of the cognitive slack decreases as a function of SOA so that no cognitive slack is created at long SOAs. Because of this cognitive slack, different patterns of results are obtained by factors affecting information processing at the perceptual processing stage (before the bottleneck) and factors affecting information processing after the central stage (after the bottleneck). When an independent variable on T2 affects a processing stage before the central bottleneck, such as perceptual difficulty, its effect is absorbed into the slack at short SOAs while the effect remains at long SOAs, resulting in an under-additive relationship between the independent variable and SOA. In contrast, when an independent variable on T2 affects a processing stage after the central bottleneck, such as word frequency, its effect is equally evident across SOAs, resulting in an additive relationship between the variable and SOA.

Fagot and Pashler (1992) found a constant amount of Stroop interference across SOAs when a color Stroop task was performed as T2, indicating that Stroop congruency affected task performance after the central bottleneck. This result is consistent with the idea that the response-selection processing stage, which has been thought to be located after the bottleneck (McCann & Johnston, 1992), is the cognitive locus of the Stroop effect (e.g., Magen & Cohen, 2002). In contrast, in Dell'Acqua, Job, Peressotti, and Pascali's (2007) experiment, picture-word interference, which refers to delayed picture naming performance to a picture presented simultaneously with a conceptually related word compared to a picture presented with a conceptually unrelated word, was found to increase with SOA. The researchers suggested that the phonological information based on the picture and word interacts before the central bottleneck.

The aim of the present study was to identify whether the Stroop dilution effect occurs at the preattentive stage, as Brown et al. (1995) argued, or at the focused attention stage, as Cho et al. (2006) asserted. T1 was a tone discrimination task, and T2 was a Stroop task. In the Stroop task, a neutral word was presented with a target color bar and a distractor color word on half of the trials, and no neutral word was presented with them on the other half of the trials. If the Stroop dilution effect is primarily caused by early perceptual crosstalk between neutral and color words at the preattentive stage, the amount of Stroop dilution would increase with SOAs because the color word could receive longer extra perceptual processing before the beginning of central processing at short SOAs compared to long SOAs. Letter identification has been found to fail more frequently when a short period of time is available for perceptual processing than when a long period of time is available (Garner & Haun, 1978; Liss, 1968). However, if Stroop dilution arises because of the selection competition between the color and neutral words after the color carrier has been selected to be processed based on its relevancy and saliency at the focused attention stage, which is located after the bottleneck, the amount of Stroop dilution would be constant across SOAs.

2. Materials and methods

2.1. Participant

To determine the desired sample size, an a priori sample size estimate was conducted using the G*Power software (Version 3.1.9.7; Faul, Erdfelder, Buchner, & Lang, 2009), with the statistical power (1 - β) set at 0.95, and an alpha level at 5%. We used its provided function for repeated measures analyses of variance (ANOVAs). As the main focus of the experiment was to detect the difference in the magnitude of Stroop dilution as a function of SOA, we selected the interaction of Stroop dilution with SOA to be the effect of most interest. Based on the effect size of $\eta_p^2 = 0.09$ and 0.44, which were the effect sizes estimated based on the *F* values of the underadditive effect in Lien, Allen, Ruthruff, Grabbe, McCann, and Remington's (2006) Experiment 1 and in Dell'Acqua et al.'s (2007) experiment, a sample size of 28 to 5 was required. However, given a possible difference in the effect-size estimation for the interaction of Stroop dilution with SOA, a larger number of participants were employed. Forty students (age range 18–37 years, 18 males) from Korea University voluntarily participated in exchange for KRW 6000 (about 5 US dollars). All participants had normal or corrected-to-normal visual acuity and color vision by self-report. Written informed consent was obtained from all participants, approved by the Korea University Institutional Review Board (KU-IRB-15-47-A-1).

2.2. Apparatus and stimuli

The experiment was programmed and presented by E-Prime software (E-Prime 2.0, Psychology Software Tools, Inc., Pittsburgh, PA, USA). Visual stimuli were presented on a 15.9-in. CRT monitor (LG IBM FLATRON 1771FT) with a refresh rate of 60 Hz and auditory stimuli were presented on speakers (PILLAR CS-3000 PLUS). Participants viewed the monitor from a distance of approximately 60 cm. Manual responses were collected via a standard computer keyboard. Vocal response times were collected with a microphone connected to a Serial Response Box (Psychology Software Tools, Pittsburgh, PA).

All stimuli were presented in a black background. The fixation point was a white color cross (0.46° × 0.46°). There were two kinds of stimuli on each trial, an auditory stimulus (S1) for the tone discrimination task (T1) and visual stimuli (S2) for the Stroop task (T2). A low (498 Hz) or high tone (661 Hz) was presented for 50 ms with no reference tone for T1. The stimuli (S2) for T2 were a bar (1.6° x 0.76°) colored in red [RGB: 255, 0, 0; CIE: x = 0.581, y = 0.346], yellow [RGB: 255,255,0; CIE: x = 0.388, y = 0.513], green [RGB: 0, 168, 20; CIE: x = 0.285, y = 0.599], or blue [RGB: 0, 0, 255; CIE: x = 0.152, y = 0.080] as a target and a color word (1.6° x 0.76°) colored in white [RGB: 255, 255, 255; CIE: x = 0.270, y = 0.297] as a distractor, which was a Korean word for red (빨강), yellow (노□), green (초록), or blue (파랑). The neutral word (1.6° × 0.76°) was also a Korean word presented in white which had the same number of syllables and a similar frequency in use as the color word: 중심 (center), 전기 (electricity), 함성 (shout), and 향수 (perfume). The color bar was always presented at the center of the display with a color word presented 1.33° above or below the target bar. A neutral word was presented in the opposite location of the color word on half of the trials and no neutral word was presented on the other half of trials (Fig. 2). The identity of a distractor was the same as that of the target stimulus (congruent) on half of the trials or different (incongruent) on the other half of trials.

2.3. Procedure

Participants were tested individually in a dimly lit sound-proof room. They performed a 36-trial practice block and three 128-trial experimental blocks. On each trial, a fixation point was presented at the center of the display for 500 ms. After a 100-ms blank interval, S1, a high or low tone, was presented. After the SOA of 50, 150, 350, or 750 ms, a color bar was presented with a color word as S2 for 250 ms to minimize the opportunity for participants to shift their attention to task-irrelevant visual events. Participants were required to press the 'f' key on the keyboard to the high tone with their left index finger and the 'j' key to the low tone with their right index finger. Then, they were instructed to execute a vocal response to the color of the target bar towards the microphone. RT2 was measured as the time from the onset of S2 to the onset of the speech sound. Immediately, an experimenter pressed a key on another computer keyboard to code the response identity that was allocated to each color: 'n' key for red, 'm' key for yellow, ',' key for green, and '.' key for blue. SOA between S1 and S2 was 50, 150, 350, or 750 ms. The next trial began after an inter-trial interval of 1000 ms. Participants were instructed to respond to S1 for the tone-discrimination task earlier than S2 and as quickly and accurately as possible to both targets. In cases of an incorrect response, 1200-ms visual displays were shown for T1 and T2 (600 ms each) with 50-ms auditory feedback.

3. Results

Trials were excluded from analyses if RT1 was shorter than 3 standard deviations (SD) below its conditional mean or longer than 3 SD above its conditional mean, or if RT2 was shorter than 3 SD below its conditional mean or longer than 3 SD above its conditional mean (2.7% of all trials). Trials were also excluded from the RT analyses if the response was incorrect on either task. The percentage error of T1 (PE1) was 1.6% and that of T2 (PE2) was 1.03% of all trials. The mean correct RT1, RT2, PE1, and PE2 were calculated for each participant as a function of neutral word (present or absent), congruency (congruent or incongruent), and SOA (50, 150, 350, or 750 ms). The mean RTs and PE for Task 1 and Task 2 in each condition are summarized in Tables 1 and 2, respectively. ANOVAs were conducted on the mean RT1, RT2, PE1, and PE2, with these variables as within-subject factors.

3.1. RT for task 1

The main effect of SOA was significant, $F(3, 117) = 21.4$, $p < .0001$, $MSe = 20{,}396$, $\eta_p^2 = 0.35$. The mean RT1 was 545, 554, 591, and 655 ms for 50, 150, 350, and 750 ms SOAs, respectively. The main effect of neutral word was significant, $F(1, 39) = 8.52$, $p = .0058$, $MSe = 1{,}930$, $\eta_p^2 = 0.18$, with the mean RT being greater when a neutral word was present ($M = 591$ ms) than when no neutral word was present ($M = 581$ ms). The interaction between congruency and SOA was also significant, $F(3, 117) = 5.63$, $p = .0012$, $MSe = 1433$, $\eta_p^2 = 0.13$, indicating that the congruency effects decreased as a function of SOA (16, 13, −5, and −13 ms for 50, 150, 350, and 750 ms SOAs, respectively). No other effect was significant for RT1. Although participants were instructed to respond to Task 1 before Task 2 as quickly as possible, the significant main effects and interactions of Task 2 factors indicated that sometimes R1 was held until R2 was at least partially prepared (Pashler, 1984; Ulrich & Miller, 2008). However, the mean RTs did not increase as SOA decreased, indicating no PRP effect for RT1.

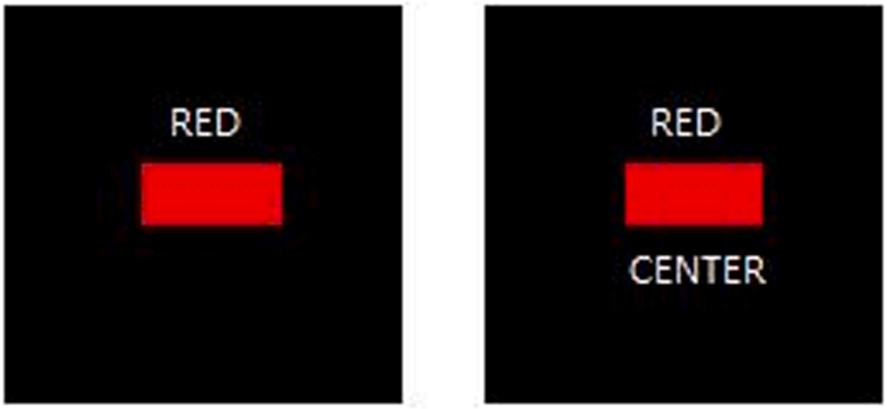

Fig. 2. Examples of target displays (in English). The left display depicts a trial in which the target bar and color word were presented. The right display depicts a trial with the target bar, color word, and neutral word.

Table 1
Mean reaction times (in milliseconds), percentages of errors of Task 1 as a function of neutral word, congruency, and SOA.

	SOA							
	50		150		350		750	
	M	PE	M	PE	M	PE	M	PE
Neutral word								
Congruent	555 (109)	3.18 (6.30)	544 (114)	1.30 (3.44)	597 (136)	1.28 (2.75)	668 (223)	0.53 (1.74)
Incongruent	563 (121)	2.65 (3.57)	561 (115)	1.94 (3.23)	587 (122)	0.74 (1.64)	656 (208)	0.56 (2.33)
Difference	**8**	**−0.53**	**17**	**0.64**	**−10**	**−0.54**	**−12**	**0.03**
No neutral word								
Congruent	536 (111)	3.31 (3.67)	534 (109)	1.28 (3.26)	591 (139)	1.39 (3.52)	654 (213)	0.84 (2.87)
Incongruent	561 (129)	3.28 (6.54)	543 (117)	0.97 (3.61)	591 (142)	1.83 (6.36)	640 (218)	0.55 (1.80)
Difference	**25**	**−0.03**	**9**	**−0.31**	**0**	**0.44**	**−14**	**−0.29**

Note. Standard deviations are shown in parentheses.

Table 2
Mean reaction times (in milliseconds), percentages of errors of Task 2 as a function of neutral word, congruency, and SOA.

	SOA							
	50		150		350		750	
	M	PE	M	PE	M	PE	M	PE
Neutral word								
Congruent	911 (140)	0.21 (0.94)	816 (188)	0.74 (1.86)	704 (162)	0.00 (0.00)	599 (124)	0.10 (0.66)
Incongruent	955 (158)	1.06 (1.86)	863 (164)	1.40 (2.85)	731 (110)	1.19 (1.95)	647 (107)	1.31 (0.39)
Difference	**44**	**0.85**	**47**	**0.66**	**27**	**1.19**	**48**	**1.21**
No neutral word								
Congruent	892 (149)	0.54 (1.46)	803 (163)	0.32 (1.13)	693 (158)	0.74 (1.64)	585 (125)	0.10 (0.66)
Incongruent	970 (144)	2.44 (4.40)	854 (165)	1.59 (3.55)	752 (139)	2.88 (4.44)	653 (104)	1.93 (2.93)
Difference	**78**	**1.90**	**51**	**1.27**	**59**	**2.14**	**68**	**1.83**

Note. Standard deviations are shown in parentheses.

3.2. PE for task 1

For PE1, SOA was significant, $F(3, 117) = 28.67$, $p < .0001$, $MSe = 6.26$, $\eta_p^2 = 0.42$. PE1 decreased as SOA increased (3.11, 1.38, 1.31, and 0.62% for SOA 50, 150, 350, and 750 ms, respectively). There was no other significant main or interaction effect for PE1.

3.3. RT for task 2

The main effect of SOA was significant, $F(3, 117) = 338.79$, $p < .0001$, $MSe = 8650$, $\eta_p^2 = 0.90$, such that the mean RT decreased as SOA increased (*M*s = 932, 834, 720, and 621 ms for SOAs of 50, 150, 350, and 750 ms, respectively), indicating a significant PRP effect. The main effect of congruency was significant, $F(1, 39) = 37.21$, $p < .0001$, $MSe = 12{,}058$, $\eta_p^2 = 0.49$, with the mean RT2 being shorter on congruent ($M = 750$ ms) than incongruent trials ($M = 803$ ms), indicating a 53-ms Stroop effect. Although the main effect of neutral word was not significant, $F(1, 39) < 1$, $p = .4053$, the interaction of neutral word and congruency was significant, $F(1, 39) = 4.42$, $p = .042$, $MSe = 4622$, $\eta_p^2 = 0.1$, indicating a Stroop dilution effect (Fig. 3). A larger Stroop effect was obtained when no neutral word was

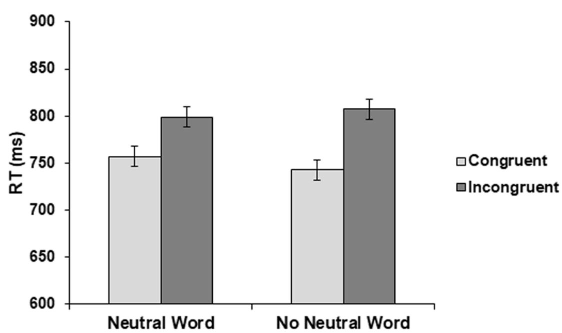

Fig. 3. Mean reaction times (RT) for congruent and incongruent trials with neutral word or without neutral word. Vertical bars represent standard errors of the mean.

presented (64 ms), $F(1, 39) = 38.50$, $p < .0001$, $MSe = 8578$, $\eta_p^2 = 0.50$, than when a neutral word was presented (42 ms), $F(1, 39) = 17.13$, $p = .0002$, $MSe = 8102$, $\eta_p^2 = 0.31$. Importantly, the interaction of neutral word and SOA was not significant, $F(3, 117) < 1$, $p = .6274$ (Fig. 4). Also, the 3-way interaction of neutral word, congruency, and SOA was not significant, $F(3, 117) < 1$, $p = .6082$ (Fig. 5). Smaller Stroop effects were obtained when a neutral word appeared with the color bar and a color word than when no neutral word appeared with them regardless of SOA (44, 47, 28, and 48 ms with a neutral word and 78, 51, 59, and 68 ms with no neutral word for SOA 50, 150, 350, and 750 ms, respectively), indicating comparable Stroop dilutions across all SOAs. Additional tests were conducted by computing Bayes factors to interpret the non-significant effects. The Bayes factors for the interaction of SOA and neutral word and the interaction of SOA, neutral word, and congruency were computed in JASP 0.10.2 software package (JASP Team, 2019) using the default prior for fixed effects (r scale prior width = 0.5) to compare the likelihoods of the null hypothesis to the competing (e.g., alternative) hypothesis. They were $BF_{01} = 41.968$ for the interaction of SOA and neutral word and $BF_{01} = 17.681$ for the interaction of SOA, neutral word, and congruency. These Bayes analyses provide evidence for the null hypothesis (Marsman & Wagenmaker, 2017). There was no other significant main or interaction effect for RT2.

3.4. PE for task 2

The main effect of congruency was significant for PE2, $F(1, 39) = 19.21$, $p < .0001$, $MSe = 15.85$, $\eta_p^2 = 0.33$, as for RT2. PE2 was higher on incongruent (1.73%) than congruent trials (0.35%). The main effect of neutral word for PE2 was also significant, $F(1, 39) = 7.81$, $p = .008$, $MSe = 6.58$, $\eta_p^2 = 0.17$, with PE2 being higher when no neutral word was presented (1.32%) than when it was presented (0.75%). The interaction of neutral word and congruency was significant, $F(1, 39) = 4.21$, $p = .047$, $MSe = 6.25$, $\eta_p^2 = 0.1$, such that the congruency effect was smaller when a neutral word was presented (0.97%) than when no neutral word was presented (1.78%). The interaction between SOA and neutral word was significant, $F(3, 117) = 3.36$, $p = .0213$, $MSe = 4.14$, $\eta_p^2 = 0.08$. The difference of PE across SOAs was 0.85, −0.12, 1.22, and 0.31% for SOA 50, 150, 350, and 750 ms, respectively. There was no other significant main or interaction effect for PE2.

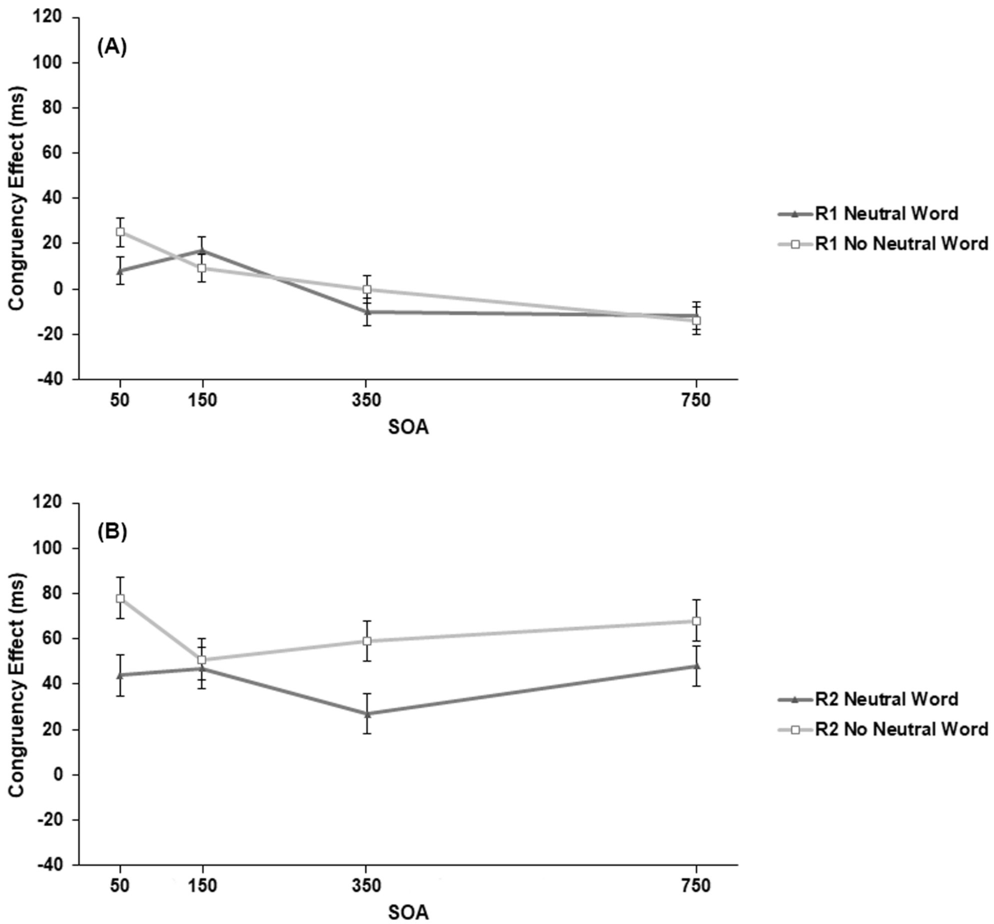

Fig. 4. The congruency effect for Task 1 (A) and Task 2 (B) as a function of neutral word and stimulus onset asynchrony (SOA; 50, 150, 350, and 750 ms). Vertical bars represent standard errors of the mean.

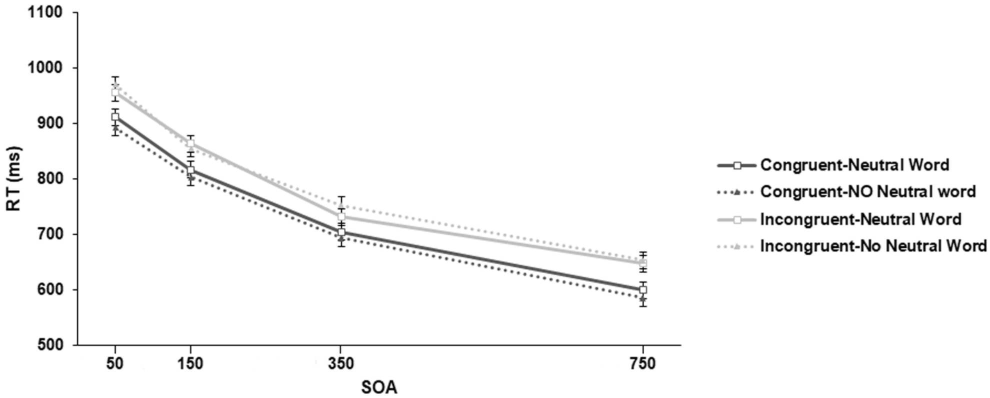

Fig. 5. Mean response times (RT) for congruent and incongruent trials in Task 2 as a function of neutral word and SOA (50, 150, 350, and 750 ms). Vertical bars represent standard errors of the mean.

4. Discussion

Although participants were instructed to respond to S1 before S2 as quickly as possible, the main effects of SOA and neutral word and the interaction between congruency and SOA were significant for RT1. Especially, the finding that RT1 increased with SOA implies that participants sometimes held R1 until R2 was prepared (Pashler, 1984). Because of this response grouping, some independent variable(s) for T1 could have affected performance for T2. However, a significant PRP effect was observed for RT2 and not RT1, which is consistent with previous PRP studies satisfying the assumption of the central bottleneck model that both tasks demand central attention (Pashler & Johnston, 1989). Also, the magnitudes of SOA effects were much larger for R2 than R1 as in other previous studies using PRP paradigms (e.g., Lien, McCann, Ruthruff, & Proctor, 2005; Pashler, 1984). Moreover, Ulrich and Miller (2008) demonstrated that response grouping does not invalidate the rationale of the central bottleneck model in their computer simulation study.

As in previous studies (Brown et al., 1995; Cho et al., 2006; Mitterer et al, 2003), a significant Stroop dilution effect was obtained for RT2. The Stroop effect was smaller when a neutral word was added to the target display than when it was not. More importantly, the amount of Stroop dilution was relatively and statistically constant across SOAs (43, 18, 32, and 26 ms for SOA 50, 150, 350, and 750 ms) in a dual task context. Bayesian statistical analyses also indicate strong evidence for the null interaction of SOA, congruency, and neutral word.

The lack of the underadditivity of Stroop dilution with SOA indicates that perceptual crosstalk among the visual items in a display at the preattentive processing stage was not the main cause of the Stroop dilution effect. If the cognitive locus of Stroop dilution is at the preattentive processing stage, the impact of the color word on task performance should have been more evident at short SOAs than at long SOAs because of the absorption of the perceptual crosstalk effect into cognitive slack at short SOAs.

According to Brown et al. (1995), the amount of Stroop dilution increases with the number of stimuli in a display and the perceptual complexity of neutral stimuli because of perceptual crosstalk increasing with them. They showed that Stroop interference decreased with the number of words in a display in their Experiment 1 and the perceptual complexity of the neutral stimuli in their Experiment 2. However, Mitterer et al. (2003) found that larger Stroop dilution was induced by letter string stimuli than by character string stimuli although they had similar perceptual complexity. Inconsistent with Brown et al.'s account, Roberts and Besner (2005) found no Stroop dilution effect when a string of symbolic characters, which was perceptually more complex than a string of alphabetic letters, was presented as a neutral stimulus.

The additivity of Stroop dilution with SOA implies that the Stroop dilution effect was due to attention competition between color and neutral words after the target was selected to be processed based on its relevancy and saliency. According to Lachter, Forster, and Ruthruff's (2004) slippage account, visual attention can be allocated to one of the task-irrelevant stimuli when there is sufficient time to shift attention to it after relevant stimuli are processed. Therefore, the magnitude of the Stroop effect decreases when a neutral word is added because the probability of the misallocation to the distractor word decreases as the number of task-irrelevant stimuli increases. Consistent with this account, distractor interference has been found to be modulated by attentional factors (Cho, Choi, & Proctor, 2012; Choi, Cho, & Proctor, 2009; Mitterer et al., 2003; Park, Kim, & Cho, 2018).

It is important to note, however, that the findings of the present study do not guarantee that focused attention is required for word recognition (Lachter, Ruthruff, Lien, & McCann, 2008; Mitterer et al., 2003). For example, in Mitterer et al.'s (2003) study, the Stroop dilution effect was eliminated but Stroop interference was not when attentional misallocation to a color word or a neutral word was prevented by a spatial cue. They argued that task-irrelevant words are processed up to a semantic level automatically regardless of attention although the amount of Stroop interference increased with the misallocation of attention to the color word superimposed on the fundamental interference, which is induced automatically. Thus, further study is necessary to clarify the automaticity of reading.

In sum, the findings of the present study are inconsistent with Brown et al.'s (1995) idea that Stroop dilution occurs because of impaired processing of the color word at the preattentive processing stage when a neutral word is presented. Moreover, many lines of evidence consistent with the present findings imply that the amount of Stroop interference is determined by the likelihood of slippage to the color word at the focused attention stage, indicating that focused attention plays an important role in the Stroop dilution effect.

CRediT authorship contribution statement

Bo Youn Park: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Yang Seok Cho:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

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