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The Effect of the Chance of a Distractor Capturing Attention on Distractor Interference*

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It has been suggested that the perceptual load induced by varying display set size is confounded with the dilution among nontarget stimuli. A flanker compatibility task was conducted to examine the nature of dilution. In Experiments 1 and 2, a target letter was presented at fixation with three or six task-irrelevant flanking letters surrounding it. Distractor interference was modulated by the number of the distracting letters in Experiment 1 and the ratio of the number of the distracting letters to the total number of the flanking letters in Experiment 2. When seven different letters were presented as a target, distracting letters, and neutral letters in Experiment 3, the number of the distracting letters modulated distractor interference. These findings are inconsistent with Tsal and Benoni's (2010) idea that dilution is due to perceptual interference in the preattentive processing stage, as well as Lavie's (1995) perceptual load theory. We argue that distractor interference is modulated by the probability of a distractor capturing focused attention.

Key words : Dilution, perceptual load, attentional capture, distractor interference

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It is widely accepted that human visual information processing passes through two different processing stages, pre-attentive and attentive stages. All inputs in the pre-attentive stage are assumed to be processed in an automatic manner, which is fast, involuntary, parallel, and independent of attentional resource (Treisman & Gormican, 1988). During this stage, basic features of the inputs, such as color, size, and orientation, are thought to be extracted. After the preattentive process, selection occurs for further processes in the attentive stage. In the attentive stage, which is characterized as a resource demanding serial process, only selected inputs are processed. However, there has been a long standing debate on the scope of the pre-attentive stage. The depth of the pre-attentive stage, which is the upper-limit of the processing stage that can be done without attention, is described as the locus of selection (Logan, 1992). The early-selection approach suggests that selection occurs based on the physical properties processed in the pre-attentive stage (e.g., Broadbent, 1958), and only selected information is identified. By contrast, the late-selection approach proposed that the meanings of stimuli are processed pre-attentively (Deutsch & Deutsch, 1963). In this perspective, all inputs are processed automatically up to the semantic level without any capacity limit. Even though the controversies on the locus of selection have continued for several decades, there have been no generally accepted criteria to distinguish the features processed with or without attention in an information processing stream.

One of the answers to the early vs. late selection controversy is the perceptual load theory proposed by Lavie and Tsal (1994). According to the theory, the amount of perceptual load is a key determinant of whether selection occurs before or after the identification process. In the case of task-relevant and irrelevant stimuli that are physically distinguishable, limited capacity attention is allocated to the task-relevant stimuli. When relevant perceptual load is low, available attentional capacity is involuntarily allocated to the irrelevant stimuli, resulting in their being processed up to a semantic level. However, when load is high, the irrelevant stimuli are not processed because of a lack of available attentional capacity after allocation of capacity to the task-relevant stimuli. That is, when the remaining resource after processing the task-relevant stimuli is sufficient to process task-irrelevant stimuli, selection occurs after the identification process. However, when the available resource is insufficient, selection occurs before the identification process.

The perceptual load theory has been supported on the basis of the findings that the impact of a task-irrelevant conflicting (congruent or incongruent) distractor is larger when the relevant perceptual load is low than when it is high. For example, in Lavie's (1995) Experiment 1, perceptual load was manipulated by varying the number of the task-relevant non-target items. A target letter (X or Z) was presented alone at one of six positions constituting a central row when the perceptual load was low or with five different non-target letters (s, k, m, n and v) when the load was high. A task-irrelevant, flanking distracting letter appeared above or below the central target row, and it was compatible, incompatible, or neutral with the target. A significant 40-ms flanker compatibility effect was obtained when the load was low, compared to a nonsignificant 4-ms effect when the load was high. This finding was replicated when a target letter was presented at one of six circularly arrayed locations, with a distracting letter placed to the right or left side of the imaginary circle (Lavie & Cox, 1997). Lavie and Cox suggested that following the allocation of attentional capacity to the relevant stimuli, spare attentional resources automatically spill over into processing of the irrelevant distractor.

Although the perceptual load theory has been widely accepted for the last 15 years, it is still unclear whether perceptual load is the key determinant of the locus of selection. For example, Paquet and Craig (1997) showed that the influence of the task-irrelevant flanker can be eliminated when perceptual load is low. Eltiti, Wallace, and Fox (2005) suggested that relative '*saliency*' of the stimuli indeed determined the extent of the irrelevant processing, regardless of perceptual load. Eltiti et al. claimed, "The perceptual load of the display does not seem to be the primary determinant of selective processing. Rather, distractor salience was the most important factor in determining distractor processing" (p. 884).

Recently, Tsal and Benoni (2010a; Benoni & Tsal, 2010) and Wilson et al. (2011) provided evidence pointing out that the most common method of manipulating perceptual load, by varying the number of the neutral stimuli presented as task-relevant inputs, is confounded with dilution among nontarget stimuli, similar to the finding that interference in the Stroop color-identification task is reduced when a neutral word is added to the target and color word relative to when no neutral word is added (Brown, Roos-Gilbert, & Carr, 1995; Kahneman & Chajczyk, 1983; Kim, Cho, Yamaguchi, & Proctor, 2008; Roberts & Besner, 2005). That is, the modulation of an interference effect by the number of the neutral stimuli occurs because of the diluted processing of the conflicting distractor, not because of the change of the locus of selection. Various accounts have been proposed to explain Stroop dilution, but Tsal and Benoni described that the null interference effect in the high perceptual load was due to perceptual degradation in processing of the displayed items (including the distractor), on the basis of Brown et al.'s (1995) early visual interference account of the Stroop dilution effect. According to this account, the impact of the task-irrelevant conflicting distractor is evident only when its representation is strong enough for lexical encoding. When the target and the flanking conflicting distractor are presented in the condition of low perceptual load, the representation of the distractor is sufficiently strong, resulting in distractor congruency. However, when the target and conflicting distractor are presented with a number of neutral stimuli, which are either relevant or irrelevant to the task at hand, in the condition of high perceptual load, the features of the stimuli interfere with each other at an early stage of visual processing before lexical encoding. This early-stage interference results in a reduced amount of lexical analysis for the conflicting distractor. For this reason, distractor interference is decreased or eliminated in the high perceptual load condition.

In Tsal and Benoni's (2010a) experiment, a target letter was presented at one of four central positions, with a peripheral conflicting flanker on either the left or right side of the target array. The target was presented alone in the low load condition and with three neutral letters in the high load condition. Critically, in the dilution condition, the target was presented with three neutral letters, as in the high perceptual load condition, but it was differentiated from the others by color. Therefore, the dilution display was basically one of low perceptual load because a target could be easily determined. However, according to Tsal and Benoni, dilution was still expected to occur in the dilution condition because processing of the neutral letters degrades processing of the distractor. The results were consistent with the perceptual load theory when it came to a significant congruence effect in the low load condition but not in the high load condition. However, distractor interference was eliminated in the dilution condition, even though the perceptual load was low, providing evidence that the basis of the null interference effect in high perceptual load is dilution among the nontarget stimuli. Benoni and Tsal (2010) claimed that the interpretation of previous research using manipulations of display size as supporting perceptual load theory size should be revised and the results attributed to dilution.

Wilson et al. (2011) agreed with Tsal and Benoni's (2010a) dilution view. However, they suggested that dilution could be due to other than visual feature interference. According to them, the search process takes place in two stages. In the first stage, which is characterized as a rapid parallel process, basic features of the stimuli are processed so that the likely location of the target is determined. In the second stage, which is characterized as a limited capacity process, focused attention is allocated to the most probable target location. Thus, the perceptual load in this stage is low because of the processing of this single stimulus, resulting in the task-irrelevant distractor and other unattended stimuli being subject to dilution. Even though Wilson et al. did not intend to explain why dilution occurs, unlike Tsal and Benoni's view, which attributes dilution to perceptual crosstalk in the first stage, they attribute dilution to processing in the second, focused attention stage.

One explanation that places occurrence of dilution in the focused attention stage is Cho, Lien, and Proctor's (2006) attentional-capture account. They suggested that processing of the task-irrelevant distractor depends on the probability that it captures visual attention in the focused attention stage. According to their account, the magnitude of distractor interference is directly modulated by the probability of the distractor capturing visual attention. If the target is defined in terms of a distinctive physical property processed in the preattentive stage, such as color in the Stroop task or location, the focused attention is most likely directed to the target initially. After initial target processing, attention shifts to another visual stimulus, if possible. Only when the distractor captures attention does it affect task performance. It has been found that when the color target and color word were presented separately, the size of the Stoop interference, which is the difference between the congruent and incongruent trials in naming performance, was affected by the exposure duration of the color word and the presence of an additional neutral word, which were thought to modulate the probability of the distracting color word capturing focused attention. However, when the target was a colored color word, these variables had no effect because the distracting color word always captured focused attention (Cho et al., 2006; Kim, et al., 2008). When the target is not defined in terms of a distinct physical property, such as in Lavie and Cox's (1997) experiment, it could be assumed that a series of attentional shifts occur from one stimulus to another until the target is found. In both cases, the probability of the distractor capturing attention decreases as the number of the neutral stimulus increases, resulting in dilution of distractor interference. Thus, unlike Tsal and Benoni's (2010a; Benoni & Tsal, 2010) view, this account attributes dilution to the processing in the focused attention stage.

Present Study

The aim of the present study is to explore whether the magnitude of distractor interference is modulated by the probability of the distractor capturing attention, as Cho et al. (2006) suggested, or the dilution caused by physical crosstalk, as Tsal and Benoni (2010a; Benoni & Tsal, 2010) suggested. In three experiments, a flanker compatibility task was conducted. Unlike previous studies, to minimize the possibility that focused attention is directed to a distracting letter before the target letter, the target location remained fixed at fixation (meaning that the perceptual load of the task-relevant stimulus is low because the other stimuli are task-irrelevant). In Experiments 1 and 2, three or six letters were presented as nontarget flanking letters in a circular array surrounding the target letter. The number of distracting letters was manipulated in Experiment 1, and the ratio of the number of distracting letters to the total number of flanking letters was manipulated in Experiment 2.

If dilution occurs because of perceptual crosstalk among the nontarget letters, the magnitude of distractor interference should be determined by the number of nontarget flanking letters because the perceptual crosstalk caused by the perceptual features of these letters is expected to increase as the number of flanking letters increases (Benoni & Tsal, 2010; Brown, Roos-Gilbert, & Carr, 1995; Tsal & Benoni, 2010a). However, if the magnitude of distractor interference is determined by the probability of a distractor capturing focused attentions, the flanker-compatibility effect should be modulated by the number of the distracting letters in Experiment 1 and the ratio of the number of distracting letters to the total number of the flanking letters in Experiment 2.

Lastly, Experiment 3 was conducted to control the influence of perceptual grouping, which may have occurred because of repeated presentation of the same letter in a display when multiple distracters were used in Experiments 1 and 2. As in those experiments, the target location remained at fixation. However, the number of flanking letters was always six. To prevent perceptual grouping from occurring, different distracting letters assigned to the same response were used when multiple distractors were presented. One, two, or four of the six flanking letters were compatible distracting letters on half of the trials and incompatible distracting letters on the other half. According to Tsal and Benoni's (2010a) dilution view, distractor interference should not be modulated by the number of the distracting letters. However, according to Cho et al.'s (2006) dilution view, distractor interference should increase as the number of the distracting letters increases.

Experiment 1

The present experiment was designed to examine whether the flanker compatibility effect is modulated by perceptual crosstalk of the nontarget features or the probability that a distracting letter captures attention. A target letter was presented at fixation, with three or six flanking letters surrounding the target in a circular array, to vary the perceptual complexity of the nontarget letter features. One or two of the flankers were the distracting letter(s) and the others were neutral letters. Because the target was distinguished from the nontarget letters by its location, according to both Tsal and Benoni's (2010a) and Cho et al.'s (2006) accounts, attention would be directed to the target letter. If dilution occurs because of the neutral words sharing visually similar features with the target letter, resulting in a perceptual crosstalk, as Tsal and Benoni's account suggests, distractor interference should be modulated by the total number of the flanking letters but not by the number of distracting letters. In contrast, if the probability of focused attention to a distracting letter modulates distractor interference, the magnitude of the effect should be more evident when the display contains two distracting letters rather than one, regardless of the total number of flanking letters.

Method

Participants Thirty-two XX University students (19 females, 13 males) from introductory psychology course participated in partial fulfillment of a course requirement. All had normal or corrected-to-normal vision.

Apparatus *E*-Prime software (Version 1.2, Psychology Software Tools, Pittsburgh, PA) was used to program the experiment. Stimuli were presented on the CRT display screen (17 in.) of an IBM-compatible microcomputer. Manual responses were made by pressing the leftmost or rightmost key of a Micro Experimental Laboratory 2.0 response box with the left or right index finger. The experiment was conducted in the light- and sound-attenuated chamber.

Stimuli The target letters were H and T (bold Franklin Gothic book font, 0.76° x 0.57°). The neutral flanker letters were Q, P, S, K and R. The distance between target letter and each of the flanking letters was 0.95°. Figure 2 shows a sample display of Experiment 1. As a fixation point, a white cross was used (Courier New font, 0.76° x 0.57°).

Procedure At the beginning of each trial, the fixation point was presented at the center of

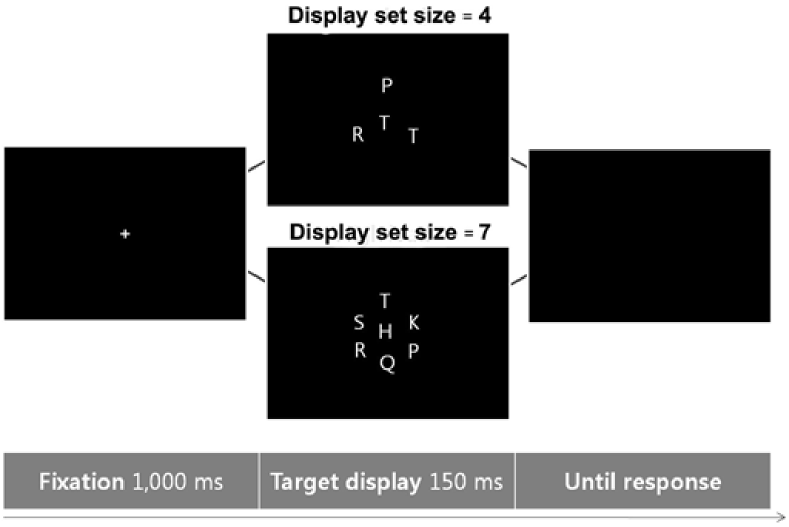

Figure 1. Example of a sequence of events on a trial in Experiment 1.

black background. After 1,000 ms, the fixation point was replaced with a target letter. Simultaneously, a circular array of three or six white flanking letters surrounding the target letter was randomly presented. When three flanking letters were present, the array contained one compatible or incompatible distracting letters and two different neutral letters or two compatible or incompatible distracting letters and one neutral letter. When six flanking letters were present, the array likewise contained one or two distracting letters (both either compatible or incompatible with the target) and five or four different neutral letters. The target letter and flanking letters were presented for 150 ms, followed by a blank screen that was displayed until a response was made (see Figure 1). The fixation point for the next trial came on 1,500 ms after the response when the response was correct or after a 150-ms 1,000-Hz feedback tone when the response was incorrect. Participants were to indicate whether the target letter was T or H by pressing the left or right response button as quickly and accurately as possible. The viewing distance was approximately 60 cm. The experiment consisted of one 16-trial practice session and 192-trial and 208-trial test sessions. A 90-s resting break was given between the two test sessions. The total running time of each experiment was about 25 min.

Results

Reaction times (RTs) shorter than 150 ms and longer than 1,500 ms were excluded from data analysis as outliers, with 0.37% of the

Table 1. Mean reaction time (RT) in milliseconds and percent error (PE) for Experiment 1

		Number of distracting letters					
		One			Two		
		C	I	I - C	C	I	I - C
Display Set Size : 4	RT (PE)	422 (3)	436 (4)	14**(1)	424 (3)	440 (4)	16**(1)
Display Set Size : 6	RT (PE)	436 (2)	435 (4)	-1 (2*)	431 (3)	441 (4)	10*(1)

Note. C = Compatible, I = Incompatible, I - C = Flanker compatibility effect, **: $p < .01$, *: $p < .05$

trials removed. Mean RT and percent error (PE) were calculated for each participant as a function of display size (four and seven), flanker compatibility (congruent and incongruent), and number of distracting letters (one and two). Analyses of variance (ANOVAs) were conducted on the RT and PE data, with those variables as within-subject variables (see Table 1).

RT analysis The main effect of flanker compatibility was significant, $F(1, 31) = 42.21$, $p < .0001$, $MSe = 6,080$, $\eta_p^2 = 0.53$. A 10-ms flanker compatibility effect was obtained. The main effect of display size was significant, $F(1, 31) = 11.23$, $p = .0021$, $MSe = 1,770$, $\eta_p^2 = 0.25$, with mean RT shorter when display size was four ($M = 430$ ms) than when it was seven ($M = 436$ ms). The interaction of display size and flanker compatibility was significant, $F(1, 31) = 7.54$, $p = .01$, $MSe = 1,594$, $\eta_p^2 = 0.23$. A 15-ms flanker compatibility effect was obtained with display size of four, $F(1, 31) = 39.74$, $p < .0001$, $MSe = 6,951$, $\eta_p^2 = 0.59$, and a 5-ms flanker compatibility effect with display size of seven, $F(1, 31) = 4.14$, $p = .05$, $MSe = 4.14$, $\eta_p^2 = 0.12$. Importantly, a significant two-way interaction between number of distracting letters and flanker compatibility was obtained, $F(1, 31) = 4.33$, $p = .0459$, $MSe = 647$, $\eta_p^2 = 0.11$. The magnitude of the flanker-compatibility effect was 7 ms with one distracting letter, $F(1, 31) = 7.89$, $p = .009$, $MSe = 1,380$, $\eta_p^2 = 0.25$, and 13 ms with two distracting letters, $F(1, 31) = 30.57$, $p < .0001$, $MSe = 5,347$, $\eta_p^2 = 0.4$. The three-way interaction with flanker compatibility, display set size and number of distracting letter was not significant, $F(1, 31) = 1.98$, $p = 0.1692$, $MSe = 347$, $\eta_p^2 = 0.06$.

Percent error analysis Overall PE was 3.25%. There was an overall compatibility effect, $F(1, 31) = 15.72$, $p = .0004$, $MSe = 123$, $\eta_p^2 = 0.35$. Error rate was 2.6% for compatible and 3.9% for incompatible flankers. However, no other term was significant.

Discussion

Experiment 1 demonstrates dilution. A greater flanker compatibility effect was obtained when the display set size was four than when it was seven. However, the number of distracting letters also influenced the magnitude of the flanker compatibility effect. The flanker compatibility effect was larger when the number of distracting letters was two (13 ms) than when it was one (7 ms). When two distracting letters were present, the magnitude of the flanker compatibility effect was significant even when the display size was seven. If dilution is due to perceptual crosstalk among the nontarget letters, as Tsal and Benoni (2010a) suggested, no distractor interference should have been obtained when the display set size was seven, regardless of the number of distracting letters. Therefore, the results are more consistent with the view that the probability of focused attention shifting to a distracting letter modulated the magnitude of the flanker compatibility effect.

Experiment 2

In Experiment 1, even though the magnitude of the flanker compatibility effect was modulated by the number of the distracting letter, the effect of display size was still evident. A 15-ms flanker compatibility effect was obtained when the display size was four, but a 5-ms flanker compatibility effect when it was seven. However, this display size effect could be due to the ratio of the number of distracting (compatible or incompatible) letters to the total number of flanking letters. That is, the ratio was one-third with one distracting letter and two-thirds with two distracting letters, respectively, when the display set size was four, compared to one-sixth and one-third, respectively, when the display set size was seven. In Experiment 2, the ratio of the number of the distracting flanker to the total number of flanker was directly manipulated. As in Experiment 1, a target was presented with three or six flanking letters surrounding the target in a circular array. However, one or two distracting letters appeared when display size was four, and two or four distracting letters appeared when display size was seven. If perceptual crosstalk is a critical determinant of whether the distracting letter is recognized, distractor interference should be modulated by the display size but not the ratio. But, if the probability that a distracting letter captures focused attention is critical, the magnitude of the flanker compatibility effect should be modulated by the ratio but not the display size.

Method

Thirty-two xx University students (21 females, 11 males) from the same participant pool as in Experiment 1 participated. The stimuli and task procedure were identical to those in Experiment 1. However, in Experiment 2, the ratio of the number of the distracting letters to the total number of the flanking letters, rather than the number of distracting letters, was manipulated. For the low ratio, one distracting letter and two neutral letters or two distracting letters and four neutral letters were presented. For the high ratio, two distracting letters and one neutral letter or four distracting letters and two neutral letters were presented.

Results

A total of 0.3% of the trials was removed from analysis using the same criteria as those in Experiment 1. Mean RT and PE were calculated for each participant as a function of display set size (4 and 7), flanker compatibility (congruent and incongruent) and distracting letter ratio (low and high). ANOVAs were conducted on the RT and PE data, with those variables as within-subject variables (see Table 2).

RT analysis A significant 13-ms overall flanker compatibility effect was obtained, $F(1, 31) = 31.08$, $p < .0001$, $MSe = 10{,}223$, $\eta_p^2 = 0.68$. Although responses tended to be faster when the display size was four ($M = 430$ ms) than when it was 6 ($M = 433$ ms), the main effect of display size was not statistically significant, $F(1, 31) = 3.84$, $p = .0592$, $MSe = 494$, $\eta_p^2 = 0.09$. Also, the main effect of distracting letter ratio approached the .05 level, $F(1, 31) = 4.08$, $p = .052$, $MSe = 806$, $\eta_p^2 = 0.15$, with RT tending to be slightly shorter when the distracting letter ratio was low ($M = 430$ ms) than when it was high ($M = 433$ ms). The interaction between distracting letter

Table 2. Mean reaction time (RT) in milliseconds and percent error (PE) for Experiment 2

		Ratio of the number of the distracting letters to the number of the flanking letters					
		Low			High		
		C	I	I - C	C	I	I - C
Display Set Size : 4	RT (PE)	424 (1)	434 (2)	9**(1)	425 (1)	437 (2)	12**(1*)
Display Set Size : 6	RT (PE)	425 (2)	436 (2)	10**(0)	426 (1)	445 (3)	19**(2**)

Note. C = Compatible, I = Incompatible, I - C = Flanker compatibility effect, **: $p < .01$, *: $p < .05$

ratio and flanker compatibility was significant, $F(1, 31) = 5.12$, $p = .0308$, $MSe = 531$, $\eta_p^2 = 0.1$. A 10-ms flanker compatibility effect was obtained when the ratio was low, $F(1, 31) = 20.02$, $p < .0001$, $MSe = 3{,}047$, $\eta_p^2 = 0.55$, and a 16-ms effect when it was high, $F(1, 31) = 50.64$, $p < .0001$, $MSe = 7{,}708$, $\eta_p^2 = 0.51$. However, flanker compatibility did not interact with display size, $F(1, 31) = 1.55$, $p = .2224$, $MSe = 255$, $\eta_p^2 = 0.05$. The three-way interaction of compatibility, display size and distracting letter ratio was not significant, $F(1, 31) = 1.74$, $p = .1969$, $MSe = 164$, $\eta_p^2 = 0.03$.

Percent error analysis Overall PE was 1.83%. The main effect of flanker compatibility was significant, $F(1, 31) = 11.97$, $p = .0016$, $MSe = 47$, $\eta_p^2 = 0.24$. A 0.9% flanker compatibility effect was obtained. Also, there was a significant main effect of display size, $F(1, 31) = 5.75$, $p = .0227$, $MSe = 25$, $\eta_p^2 = 0.14$. PE was 1.5% with three flanking letters and 2.1% with six flanking letters. The interaction between flanker compatibility and distracting letter ratio was significant, $F(1, 31) = 6.29$, $p = .0176$, $MSe = 14$, $\eta_p^2 = 0.08$. There was a nonsignificant 0.4% flanker compatibility effect when the ratio was low, $F(1, 31) = 1.02$, $p = .318$, $MSe = 5.07$, $\eta_p^2 = 0.03$, compared to a significant 1.3% effect when it was high, $F(1, 31) = 11.38$, $p = .002$, $MSe = 56$, $\eta_p^2 = 0.36$. Other terms were not significant.

Discussion

The size of the flanker compatibility effect increased as the distracting letter ratio increased from one-third (10 ms) to two-thirds (16 ms), regardless of whether the display size was four or seven, suggesting that the probability of a distracting letter capturing focused attention was a key determinant for the magnitude of distractor interference. However, this effect was not modulated by display size. When the ratio was one-third, the flanker compatibility effect was 9 ms with three flanking letters and 10 ms with six flanking letters, $F(1, 31) < 1.0$, $p = .795$, $MSe = 5.69$, $\eta_p^2 = 0.002$. When it was two-thirds, the effect was 12 ms and 19 ms, respectively, $F(1, 31) = 1.75$, $p = .195$, $MSe = 416$, $\eta_p^2 = 0.05$. That is, when the ratio of the number of distracting letters to the number of flanking letters was fixed, no display set size effect was obtained, suggesting that the perceptual crosstalk did not contribute to determining the size of distractor interference.

However, because multiple identical distracting letters were presented in each trial in Experiments 1 and 2, there is a possibility that identical distracting flankers were grouped together so that increasing the number of the flanking letters did not increase the perceptual complexity of the letter features. To avoid this perceptual grouping problem, multiple different distracting letters were used in Experiment 3.

Experiment 3

In Experiment 3, flankers were presented with all different letters in order to prevent grouping by eliminating the display contained the same letters in a given trial. Unlike the previous experiments, the effect of the ratio of the number of the distracting letters to the total number of flanking letters was examined in a large display size. To vary the probability of shifting attention to a distracting letter, one, two, or four distracting letters appeared on each trial. The total number of the flanking letters was always six. The main purpose of Experiment 3 was to examine whether the probability of attention shifting to a distracting letter determines the size of distractor interference when seven different letters are presented as target, distracting, and neutral flanking letters. If the size of distractor interference is determined by the probability that a distracting letter captures attention, distractor interference should increase with the number of distracting letters. However, if dilution is due to early visual interference, no flanker compatibility effect should be obtained regardless of the number of distracting letters.

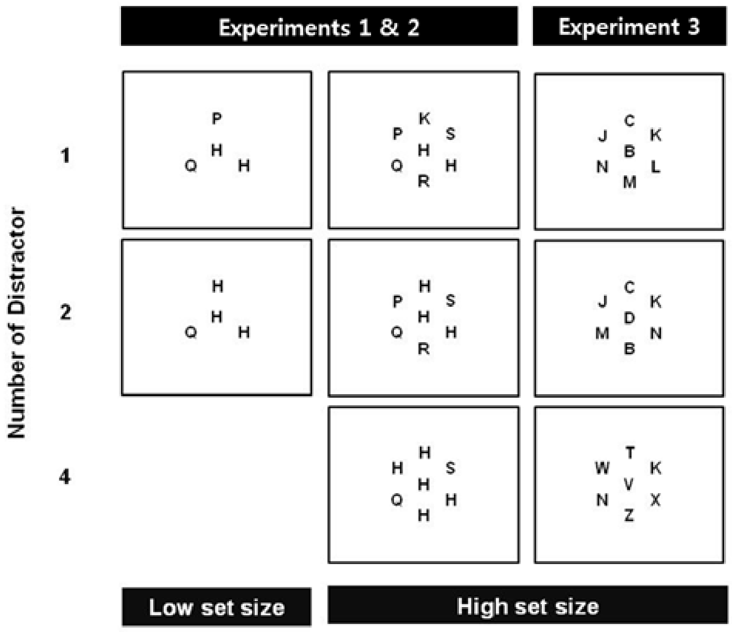

Figure 2. Examples of compatible display used in experiments

Method

Thirty-two new xx University students (19 females, 13 males) from the same participant pool as in the previous experiments participated. The procedure was identical to that of Experiment 2, with the following exceptions. The display size was always seven. A circular array of six flanking letters and one centered target letter were presented on each trial. One, two or four of the six flanking letters were compatible or incompatible distracting letters. The target letters were B, C, D, F, G, T, V, W, X, and Z and the neutral letters were J, K, M, N, and L. To eliminate perceptual overlap, seven different letters were presented on each trial. Participants were instructed to press one button to the target letter of B, C, D, F and G and the other button to the target letter of T, V, W, X and Z. (see Figure 2) The target-response mapping was counterbalanced across participants, who took part in one 36-trial practice session and two 180-trial test sessions. A 90-s rest break was given between the two test sessions. The total running time of the experiment was about 20 minutes.

Results

0.38% trials were excluded from analysis as outliers using the same criteria as those in the previous experiments. Mean RT and PE were calculated for each participant as a function of flanker compatibility (congruent and incongruent) and the number of distracting letters (1, 2 and 4). ANOVAs were conducted on the RT and PE data, with those variables as within-subject variables (see Table 3).

RT analysis A significant 8-ms flanker compatibility was obtained, $F(1, 31) = 12.66$, $p = .0012$, $MSe = 3{,}008$, $\eta_p^2 = 0.25$. Importantly, the interactions between number of distracting letters and flanker compatibility was significant, $F(2, 31) = 8.09$, $p = .0008$, $MSe = 1{,}207$, $\eta_p^2 = 0.2$. The flanker compatibility

Table 3. Mean reaction time (RT) in milliseconds and percent error (PE) for Experiment 3

		Ratio levels of distracting letters		
		One Sixth	Two Sixths	Four Sixths
C	RT (PE)	507(3)	497(3)	497(2)
I	RT (PE)	506(3)	508(4)	512(4)
I - C	RT (PE)	-2(1)	11**(1*)	15**(2**)

Note. C = Compatible, I = Incompatible, I - C = Flanker compatibility effect, **: $p < .01$, *: $p < .05$

effect was -2 ms when one distracting letter was present, $F(1, 31) < 1.0$, but it increased to 11 ms when two distracting letters were present, $F(1, 31) = 12.77$, $p = .0007$, $MSe = 1{,}906$, $\eta_p^2 = 0.26$, and 15 ms when four distracting letters were present, $F(1, 31) = 23.17$, $p < .0001$, $MSe = 3{,}459$, $\eta_p^2 = 0.35$.

Percent error analysis Overall PE was 3.14%. A significant main effect of flanker compatibility was found, $F(1, 31) = 14.4$, $p = .0006$, $MSe = 65$, $\eta_p^2 = 0.3$. A 1.1% flanker compatibility effect was obtained. This flanker compatibility effect was modulated by number of distracting letters, $F(2, 31) = 2.88$, $p = .06$, $MSe = 8$, $\eta_p^2 = 0.09$. The flanker compatibility effect was 0.7% with one distracting letter, $F(1, 31) = 2.73$, $p = .104$, $MSe = 7.45$, $\eta_p^2 = 0.11$, 0.8% with two distracting letters $F(1, 31) = 4.13$, $p = .046$, $MSe = 11$, $\eta_p^2 = 0.1$, and 2.0% with four distracting letters, $F(1, 31) = 22.7$, $p < .0001$, $MSe = 62$, $\eta_p^2 = 0.3$.

Discussion

The flanker compatibility effect increased as the number of distracting letters increased, even though seven different letters were presented in the stimulus display. Again, the results are not consistent with the prediction drawn from Tsal and Benoni's (2010a; Benoni & Tsal, 2010) dilution view. If the six different flanking letters degrade each other's feature representation at an early visual processing stage, as Tsal and Benoni suggested, any amount of distracting letters should have no impact on task performance because the amount of the lexical analysis of a distractor is reduced. However, the flanker compatibility effects evident with the two or four distracting letters provide evidence that attentional capture to a distracting letter occurred. By this account, focused attention shifts to one of the flanking letters surrounding the target after initial processing of the target. When a distracting letter captures attention, it causes conflict. However, when a neutral letter captures attention, no distractor interference occurs. Thus, as the number of the distracting letters increases, the probability of a distracting letter capturing focused attention increases, resulting in the flanker compatibility effect increasing with the number of the distracting letters.

General Discussion

The present study demonstrates two critical findings. First, the magnitude of interference from the distracting letter increased with the ratio or number of the distracting letters regardless of the display size. The size of the flanker compatibility effect increased as a function of the number of the distracting letter in Experiment 1 and as a function of the ratio of the number of the distracting letters to the total number of the flanking letters in Experiment 2. When seven different letters were presented on a given trial to avoid perceptual grouping from occurring in Experiment 3, distractor interference increased as a function of the number of distracting letters. Second, when the ratio of the distracting letters was fixed (i.e., either one-third or two-thirds in the present study), the magnitude of the flanker compatibility effect was not modulated by the display size in Experiment 2. These results are inconsistent with predictions drawn from Tsal and Benoni's (2010a; Benoni & Tsal, 2010) dilution view. If the number of nontarget (non-attended) stimuli increases the amount of perceptual crosstalk among those stimuli at an early visual processing stage, then distractor interference should remain the same regardless of the number distracting letters, which it did not. Instead, the results imply that dilution occurs in the focused attention stage. Specifically, the size of distractor interference is modulated by the probability that focused attention is directed to a distractor.

Dilution Accounts

Tsal and Benoni (2010a; Benoni & Tsal, 2010) and Wilson et al. (2011) provided evidence indicating that the perceptual load manipulated by varying the number of the neutral stimuli presented as task-relevant inputs is confounded with dilution of the peripheral distractor by the neutral stimuli. Tsal and Benoni described the null interference effect in the high perceptual load as not being due to an increase of perceptual load, but to perceptual degradation in processing of the nontarget stimuli. As the number of the nontarget stimuli increases, the amount of the perceptual crosstalk increases, reducing the amount of lexical analysis for the distractor. Thus, according to Tsal and Benoni's dilution view (which is based on Brown et al.'s (1995) early interference account of the Stroop dilution effect), the distractor interference should be modulated by factors affecting the amount of the perceptual crosstalk among the nontargets before lexical analysis, such as the number of the nontarget stimuli or their visual complexity (e.g., Brown et al., 1995). However, in the present study the size of distractor interference was not modulated by the number of the nontarget letters but by the ratio of the number of distracting letters to the number of nontarget stimuli. Moreover, it has been found that the amount of dilution is not related to visual complexity (Mitterer, La Heij, & Van der Heijden, 2003; Roberts & Besner, 2005). For example, Roberts and Besner showed that

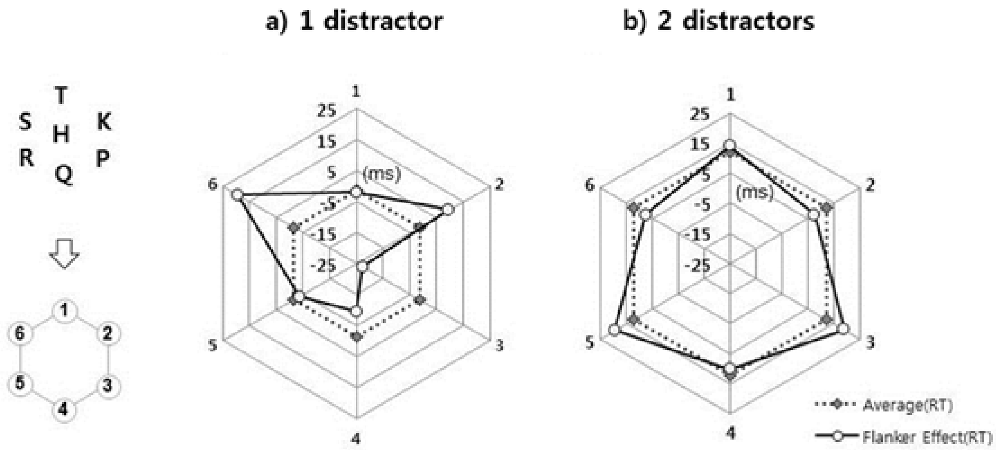

Figure 3. Flanker compatibility effect (incompatible – compatible) as a function of conflicting distractor position in Experiment 3. The number in a circle denotes corresponding position of the display. The vertical axis indicates the amount of the flanker compatibility effect. The empty circle indicates the size of flanker compatibility effect by the location of distractor. The gray diamond implies the average amount of flanker compatibility effect irrespective of the location of the distractor. a) shows the flanker effect when there was only one distractor. b) represents the flanker effect when one of two distractors was presented at the given location.

distractor interference was modulated by the nature of the target stimulus but not by its visual complexity.

It should be noted that the effect of the number of conflicting distractors could have been due to the summed activation of their representations increasing with the number of distractors, even though early visual interference occurred. If early visual interference occurred among distractors, the same amount of the perceptual crosstalk caused by the perceptual features of these letters would be expected to occur across all distractors. Thus, regardless of the position of the conflicting distractor, the same size of flanker compatibility effect should be expected. On the other hand, the attentional capture account assumes that the amount of interference varies according to the position of the conflicting distractor in a given display if the focus of visual attention tends to shift to a specific location. In Experiment 3, the sizet of the flanker compatibility effect in the RT data varied across the position of the conflicting distractor. When one conflicting distractor was presented (see Figure 3a), a significant 19-ms flanker compatibility effect was obtained at the upper-left position, $F(1, 31) = 4.06$, $p = .0527$, $MSe = 5{,}997$, $\eta_p^2 = 0.12$, but not at the other positions. When two conflicting distractors were presented (see Figure 3b), the flanker compatibility effect was significant when a conflicting distractor was presented at the upper, $F(1, 31) = 4.31$, $p = .0463$, $MSe = 15{,}673$, $\eta_p^2 = .12$, lower-left, $F(1, 31) = 5.39$, $p = .027$, $MSe = 113{,}14$, $\eta_p^2 = .15$, and lower-right positions, $F(1, 31) = 7.6$, $p = .01$, $MSe = 241{,}71$, $\eta_p^2 = .2$.

This asymmetry pattern was also observed when four conflicting distractors were presented (Figure 3c). That is, significant interference was obtained when conflicting distractor was presented at the upper, $F(1, 31) = 5.5$, $p = .0256$, $MSe = 29476$, $\eta_p^2 = .15$, lower, $F(1, 31) = 13.62$, $p < .001$, $MSe = 48{,}369$, $\eta_p^2 = .31$, and upper-right positions, $F(1, 31) = 4.43$, $p = .0436$, $MSe = 11{,}487$, $\eta_p^2 = .12$. This result indicates that the amount of distractor interference was influenced by the position of the conflicting distractor. Although, the reason of this asymmetric pattern of interference is unclear at present, it clearly manifests that attentional capture in the second stage was involved in this phenomenon. Durgin, Doyle, and Egan (2008) reported involuntary upper-left gaze bias for a

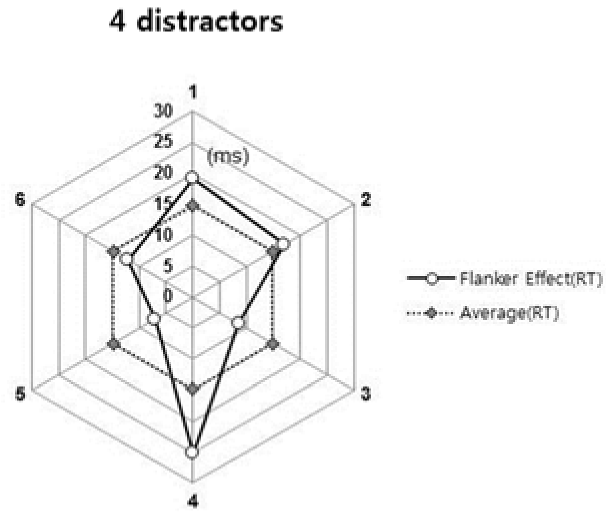

Figure 3 (c). The flanker compatibility effect (incompatible - compatible) as a function of location of distractor when the number of distractor was four in Experiment 3. In the overall trials, six irrelevant letters were presented which involved four distracting and two neutral letters in randomly distributed locations. The empty circle at the six different positions denotes the flanker effect when one of the four distractors was not presented at the given location. For example, the empty circle at the location at the '4' indicates the average flanker effect when none of distracters was presented at the lower location. The gray diamond refers the average amount of flanker effect regardless of the location of distractor.

reverse Stroop task, in which participants had to identify which circle in an array of six colored circles matched the color designated by a centered word, which was presented in a distracting color. They interpreted the upper-left bias was routine eye-gaze strategy which usually occurred unconsciously (see also Dark, Vochatzer, & VanVoorhis, 1996). We conclude that this location-specific attentional priority is a common observation in shifting visual attention. Thus, dilution was unlikely due to early visual interference among distractors before lexical encoding, as Tsal and Benoni (2010a; Benoni & Tsal, 2010) suggested.

Wilson et al. (2011) found that increasing the display size increased dilution regardless of the relevancy of the additional letters, whereas increasing the number of cued locations increased distractor interference. This result is inconsistent with Lavie and Tsal's (1994; Lavie, 1995) perceptual load theory, which suggests that the perceptual load imposed by the relevant stimuli determines whether a distractor is processed. However, unlike Tsal and Benoni (2010a; Benoni & Tsal, 2010), Wilson et al. attributed dilution to the influence of the display size on processing in the focused attention stage. Some of the accounts proposed to explain the Stroop dilution effect also claim that dilution is a consequence of the focused attention stage processes. For example, Kahneman and Chajczyk's (1983) attentional capture account assumes that only one word can be processed at a time. When a neutral word and a color word are presented with a color bar, just one of the two words captures focused attention. Conflict occurs only when the color word captures focused attention. Thus, the magnitude of distractor interference is primarily determined by the probability of a distractor capturing focused attention (Cho et al., 2006; Choi, Cho, & Proctor, 2009; Kim et al., 2008). Because the probability of a distractor capturing focused attention decreases as the number of the stimuli in a display increases, regardless of the relevancy of the additional stimuli, the attentional capture account is consistent with the finding that the size of distractor interference decreased as a function of the number of the stimuli.

Perceptual load theory

In response to the dilution view proposed by Tsal and Benoni (2010a), Lavie and Torralbo (2010) suggested that the reduced distractor effect in the dilution condition in Tsal and Benoni's experiments was due to involuntary allocation of spare capacity to some of the task-relevant nontargets in a display, resulting in the elimination of distractor processing. In Lavie and Torralbo's experiment, a colored target and five nontarget letters were presented in a circular array with a peripheral letter. The influence of the distractor was larger when two distractors were presented at each side of the colored target in the circle with a neutral peripheral letter than when distractor was presented at the peripheral location. According to Lavie and Torralbo, the reduced distractor interference in the dilution condition is due to a spillover of spare capacity to some of the search nontarget letters instead of the peripheral distractor, but not to perceptual crosstalk among the nontarget letters and peripheral distractor.

However, as Tsal and Benoni (2010b) pointed out, this *spillover hypothesis* has a lack of parsimony. The perceptual load theory contends that the extent of irrelevant processing is determined by the amount of attentional capacity required for relevant stimuli processing, and it is premised on the idea that a relatively large amount of attentional capacity is required to find a target among a large number of different neutral letters than to find it among identical meaningless symbols (i.e., o). Hence, the number of different neutral letters in search array varies to modulate the level of the perceptual load. In most studies, a load-induced display has multiple relevant letters around fixation, with a single irrelevant distracting letter in peripheral area. During last 15 years, the same display has been used without any modification in many studies. In other words, the perceptual load theory has been supported only by a specific task procedure. Thus, there are ample possibilities that the degree to which a distractor is processed is determined by other than perceptual load. For example, focused attention is likely to be captured by a salient distractor regardless of the perceptual load (Biggs & Gibson, 2010; Eltiti et al., 2005; Paquet & Craig, 1997).

According to the primary definition of perceptual load suggested by Lavie (1995; Lavie & Tsal, 1994), only the number of the task-relevant stimuli is supposed to be taken into account. However, in the present study, distractor interference was modulated by the number of the task-irrelevant letters in a display, especially the number of the task-irrelevant distracting letters. Moreover, in experiments by Kyllingsbæk, Sy, and Giesbrecht's (2011), in which participants performed a visual working memory task, peripheral distractor interference was larger with two distractors than with one, regardless of the relevant perceptual load. Moreover, Kyllingsbæk et al. found that distractor interference was more evident at longer exposure durations than at shorter exposure durations. For perceptual load theory to accommodate these findings, the theory must make additional assumptions regarding the situations in which multiple task-irrelevant stimuli are present, as well as processing of multiple distracting stimuli.

Conclusion

The most vital finding of the present study is that distractor interference increased as the ratio of the number of distracting letter to the total number of task-irrelevant letters in a display. This finding is inconsistent with Tsal and Benoni's (2010; Benoni & Tsal, 2010) idea that dilution occurs because of perceptual crosstalk among the nontarget letters in the preattentive stage. We agree with those authors' claim that the finding of decreased distractor interference with increasing display size is due to dilution. However, the results of the present study show that dilution is a consequence of a decreased probability that a distractor captures focused attention in the focused attention stage. Because this probability is determined by factors including the ratio of the distracting stimuli, the exposure duration of the distractor, and its salience, the amount of distractor interference is modulated by these variables rather than by the relevant perceptual load.

The present study was unfortunately unable to directly test Lavie's (1995; Lavie & Torralbo, 2010) perceptual load theory, because the spillover hypothesis does not provide any theoretical prediction for the situation in which multiple task-irrelevant and distracting letters are presented. However, load theory is insufficient to explain the allocation of attentional capacity to stimuli in various types of stimulus displays without additional assumptions. Most important, Lavie and Torralbo's spillover hypothesis is not able to provide the answer for the question regarding the locus of selection or the scope of the preattentive process, for which perceptual load theory (Lavie, 1995; Lavie & Tsal, 1994) was originally intended to provide the answer (Tsal & Benoni, 2010b).

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방해 효과에 미치는 방해자극의 주의 획득 기회의 영향

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조 양 석 / 고려대학교

화면에 제시된 set-size의 크기를 변화시켜 유도된 지각부하의 효과는 비목표자극들 사이의 희석 효과와 혼입된다고 알려져왔다. 희석효과의 특성을 알아보기 위해 수반자극과제를 시행하였다. 실험 1과 2에서는 목표 글자 자극이 응시점에 제시되었던 곳에 3개, 또는 6개의 과제 비관련 수반 글자와 함께 제시되었다. 실험 1에서는 방해자극에 의한 방해 효과는 방해 글자의 숫자에 의해 영향을 받았으며, 실험 2에서는 그 효과가 전체 과제 비관련 수반 글자의 수에 대비한 방해 글자의 수에 의해 영향을 받았다. 7개의 서로 다른 글자가 자극, 방해자극, 그리고 중성 자극으로 제시된 실험 3에서는 방해 글자 자극의 개수에 의해 방해효과의 크기가 달라졌다. 이러한 결과는 희석 효과가 전주의처리 과정에서 지각적 방해로 나타난다는 Tsal과 Benoni(2010)의 견해와 불일치 하며, Lavie(1995)의 지각 부하 이론으로도 설명 불가능하다. 방해효과의 크기는 방해자극이 초점주의를 획득할 확률에 의해 결정되는 것으로 보인다.

중심어 : 희석효과, 지각적 부하, 주의 획득, 방해효과