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Attentional Capture as an Alternative view of Perceptual Load Theory and Early-Visual Crosstalk Account

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The perceptual load theory (Lavie & Tsal, 1994) and the dilution account (Tsal & Benoni, 2010) have been proposed to explain the phenomenon that the degree of irrelevant information processing decreases as the relevant stimulus-set size increases. The present study investigated the nature of the set-size effect on processing of task-irrelevant information. Under high perceptual load with a single distractor, no congruency effect was replicated in the present study. However, importantly, the congruency effect increased as the number (ratio) of distractor increased (Experiments 1 & 2). In dilution condition (Experiment 3), a larger congruency effect was found when a conflict distractor was located at the task-relevant array than at a task-irrelevant peripheral position, which is consistent with previous findings. However, an additional presentation of a distracting letter did not produce a larger congruency effect. These results indicate that the perceptual load effect by increasing the number of task-relevant items is a result of a reduced probability of attentional capture by a conflicting distractor. Furthermore, this selective processing occurs at a focused attention stage which implies that early-visual crosstalk is not an alternative explanation.

Key words : Dilution, Perceptual load, Attentional capture, Conflict, Visual crosstalk

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Our visual system is required to continuously focus on goal-related information while filtering out to-be-ignored information. This is necessary for successful object recognition because we could not fully process numerous amount of visual input, which falls on our retina. Traditional *'filter theory'* suggests that only a part of visual information could pass a sensory filter and receive further processing (e.g., Broadbent, 1958). According to the two-stage model (Hoffman, 1979; Neisser, 1967), visual search is described as the composition of two different modes of processing: 'pre-attentive' and 'focused attention' stages. In the pre-attentive stage, all of the visual inputs are expected to be processed in a parallel way. Based on the information obtained in this first stage, those which bear physical resemblance to the targeted object receive the serial comparison in the second stage. Regarding the scope of visual information processing which assumed to occur at the first stage, the early- and late- selection views provide different opinions.

The early selection view was proposed to advocate that identification process is subject to limited capacity (Broadbent, 1958). In this perspective, irrelevant information is filtered out in the first stage by basic features such as location, color, luminance, orientation, or size. On the other hand, the late selection view (Deutsch & Deutsch, 1963) suggested that identification process is not subject to the limited capacity, resulting in all of the stimuli reaching to semantic processing in a parallel manner in the first stage. Thus, selection is expected to occur at the second stage of information processing once object identification has completed. In contrast, the early selection view suggests that only selected information can be processed with the deployment of visual attention. In this perspective, the meaning of a visual object could be extracted only when it receives focused attention as a consequence of serial comparisons. The controversy between those two accounts has continued for several decades and remained a central tenet of visual attention.

Meanwhile, a hybrid model named the perceptual load theory (Lavie & Tsal, 1994) was introduced as an alternative explanation for the early *vs.* late selection debate. Lavie and Tsal defined the term perceptual load as "the number of unit" or "the amount of information required to process each unit in order to produce the response" (p.185). The perceptual load theory assumes that attention has limited capacity and it processes stimuli until it runs out of resource. Ascribing the capacity dependent nature of attention, the load theory suggested that the perceptual load is the key determinant factor for the locus of selection (Lavie, 1995). According to the load theory, the amount of attentional resource is enough to fully process all of the stimuli in the low perceptual load; in other words, late selection occurs. Thus, the task irrelevant information is expected to produce a significant interference effect in the low perceptual load. However, under high perceptual load, the amount of attentional resource is compelled to be exhausted while processing relevant stimuli leaving no residual resource to process irrelevant stimuli. The load theory expands its idea that, if there is a clear physical distinction between the relevant and irrelevant stimuli, the selection occurs at relatively earlier stage of visual processing stream. In this notion, task irrelevant information is expected to be eliminated in pre-attentive stage results in a null congruency effect. For example, Lavie (1995) demonstrated how the perceptual load determines the extent of task irrelevant information processing. In her Experiment 1, the perceptual load was manipulated by varying the relevant display size. Participants had to respond to 'X' or 'Z' which was located at the central row of the display while ignoring a peripheral distractor presented above or below the target array. The relevant set size was one for low load and six for high load including five different non-target letters. The incompatible peripheral distractor interfered with target processing only for low perceptual load but not for high perceptual load.

A number of studies have supported the perceptual load theory in aspects of various attentional phenomena such as inattentional blindness (Cartwright-Finch & Lavie, 2006), negative priming (Lavie & Fox, 2000), emotional processing (Bishop, Jenkins & Lawrence, 2007; Mitchell et al., 2007), invisible object processing (Bahrami et al., 2007, 2008) and others (Forster & Lavie, 2007, 2008, 2009, 2011; Gibson & Bryant, 2008; Lavie, 2005; Muggleon et al., 2008). It is noteworthy that most of those studies have manipulated perceptual load by varying display size and a critical problem inherent in the general application of the perceptual load theory is there. Benoni and Tsal (2010; also see Tsal & Benoni, 2010a; 2010b) suggested that increasing the display size indeed results in dilution in which degrade the feature representations at an early visual processing stage. That is, because the amount of dilution increases with the number of display size, the congruency effect between the target and peripheral distractor decreases as the display size increases.

The idea of feature dilution (Tsal & Benoni, 2010a; 2010b, Benoni & Tsal, 2009; 2010) was originated from the early-visual interference account (Brown, Roos-Gilbert, & Carr, 1995) which was initially proposed to account for 'Stoop dilution' effect (Kahneman & Chajczyk, 1983). Stroop dilution refers to the phenomenon that the additional presentation of a neutral word (e.g., CUTE) halves the magnitude of the Stroop effect relative to the effect obtained without a neutral word when a color carrier and color word are presented separately. The early-visual interference account suggested that visual information from multiple channels interact each other producing perceptual interference at the parallel feature extraction stage (see Bjork & Murray, 1977; Estes, 1972; 1974). In this sense, dilution is not limited to the meaningful stimulus (e.g., word), but any visual stimulus could produce degradation in the encoding of distractor. On the other hand, Kahneman and Chajczyk (1983) interpreted that Stroop dilution is due to a reduced probability that the color word captures attention. In this point of view, attention has a unitary channel which can process one object at a given time. Therefore, a neutral word decreases the probability that the color word captures attention. This reduced probability eventually results in decrease in the size of the Stroop effect.

Benoni and Tsal's (2010; Tsal & Benoni, 2010a; 2010b) dilution account suggested that the absence of distractor interference under high perceptual load was due to the additional presence of neutral letters causing early visual-crosstalk, resulting in degradation of the lexical representation of the distractor. In their Experiment 1, a target was presented at one of four positions of an imaginary square with three horizontal bars ("-") in low load and three neutral letters in high load displays. In dilution trials, a target was colored in red or green among white non-target letters in a high load display. The number of to-be-searched item was one since there was no need to search the target exhaustively. Thus, the level of perceptual load was considered as low but additional non-target letters were likely to produce feature dilution. As the previous studies have found, there was a significant congruency effect under low load but no effect under high perceptual load. Importantly, the dilution display did not produce a meaningful congruency effect although it was claimed as low perceptual load. They concluded that decreased distractor interference under high perceptual load was actually due to feature dilution.

To investigate the natures of dilution or the effect of perceptual load, the number of items in a given display has been manipulated. In the Stroop dilution task, participants are required to ignore an additionally presented neutral word because the task goal is to name the color bar. In the study of perceptual load, however, participants have to scan the letters on the task-relevant array in order to find the targeted letter. In summary, it has been suggested that increasing the number of non-target objects causes dilution while increasing the number of task relevant objects results in the perceptual load effect. Therefore, it is possible to assume that, even dilution and the effect of perceptual load share a somewhat similar phenomenon, they are possibly based on different mechanisms.

Wilson, Muroi, and Macleod (2011) tested how the relevant and irrelevant display size manipulations influence the extent of distractor processing. They have used the paradigm used by Lavie and Cox (1997) but presented the pre-cue indicating the potential target location. In their study, the interference effect decreased as the overall display size increased, but it was not influenced by whether increased items were relevant (pre-cued) or irrelevant (non-cued). In addition, the extent of interference increased with the number of cued items regardless of the display size. Based on these results, they proposed the second stage dilution account based on the two-stage model of visual search (Neisser, 1967; Hoffman, 1979) as an alternative to the perceptual load theory. According to their view, increased number of the cued item raised the decision noise about the target location. This uncertainty increased the time spent on the pre-attentive parallel processing, resulting in an increased likelihood of distractor processing at the second stage of focused attention.

Cho, Lien, and Proctor (2006) also reported the evidence of the second stage dilution to explain Stroop dilution. Their *revised attentional-capture account* described Stroop dilution as a result of the decreased probability that the color word captures attention after the initial orientation to the color carrier when the color word is presented as a distractor (also see Kim et al., 2008). For example, in their Experiment 5A, a color bar (or neutral word) was presented as the color carrier at the center of the display with a congruent or incongruent color word appearing above or below the color carrier. Critically, the display duration was manipulated within the range of 100 msec to 250 msec. When the color carrier was a color bar, the size of the Stroop effect increased as the display duration increased. They concluded that the longer the display duration the higher the chance of color word capturing attention resulting in a large Stroop effect.

Recently, Suh and Cho (2013) suggested that the chance of the attentional capture modulates the interference from an irrelevant distractor. In their experiment 2, in which participants had to press buttons according to the centrally presented letter (‘T’ or ‘H’) while ignoring three (set size = 4) or six (set size = 7) surrounding flankers, the flanker compatibility effect (incompatible - compatible) increased as the ratio of the conflicting letter increased. They concluded that the perceptual load itself could not be the major determinant for the locus of selection. Unfortunately, however, the result provided a partial evidence of the attentional capture overriding the perceptual load because their study only focused on the selective stimulus processing under low perceptual load.

So far, the dilution account has been supported as an alternative explanation for the perceptual load theory (Benoni & Tsal, 2009; 2010, Tsal & Benoni, 2010a; 2010b; Wilson et al., 2011). However, the visual processing stage at which dilution is expected to occur remained questionable. The present study aimed to test the validity of the perceptual load theory and specify the visual processing stage wherein the dilution would occur centered on the two major views; attentional capture and early-visual interference account.

The present study was conducted in an attempt to demonstrate the role of focused attention under high perceptual load. A number of studies have observed a meaningful distractor interference effect under high perceptual load when the distractor was abruptly onset object (see Cosman & Vecera, 2010; Eltiti, Wallace, & Fox, 2005), familiar object (He & Chen, 2010), and negative picture (Sand & Wiens, 2011). It has been well known that such stimuli have attentional priority which usually captures visual attention involuntarily. Even though those studies did not discuss about the possibility of attentional capture, it is plausible to assume that some objects which automatically capture attention are resistant to perceptual load. Thus, it is important to look at how the probability of attentional capture influences our visual perception under high perceptual load. Unlike the previous studies that varied the property of distractor (saliency, familiarity, etc), the present study manipulated the number of distractors under high perceptual load. We expect that multiplying the number of distractor could serve systematic understanding of how selective attention determines what we are seeing under highly complex visual display.

The high load display of Lavie and Cox's (1997) experiment was used with an exception of the way to present task-irrelevant stimuli in Experiments 1 and 2. In Experiment 1, one, two, or four task-irrelevant distractors were presented at peripheral region. In Experiment 2, the number of peripheral letters was fixed as four; one or two distractors were presented along with three or two neutral letters. In addition, to distinguish the relevant and irrelevant stimuli more clearly, the colors of the relevant and irrelevant stimulus arrays were differentiated. The perceptual load theory expects no interference effect by conflicting distractors under high perceptual load. On the contrary, both Benoni and Tsal's (2010) dilution account and Cho et al.'s (2006) attentional capture view predict increases in the distractor interference as the number of distractor increases. However, the former attributes the dilution effect to early perceptual interference, while the latter to the probability that a conflicting distrator captures attention. To test whether dilution occurs at first pre-attentive or second focused attention stage, we replicated Benoni and Tsal (2010) while varying the number and location of distractor in Experiment 3. When the number of distractor is fixed, the early-visual interference view expects a uniform amount of interference whether the distractor located at relevant or irrelevant array. However, the attentional capture account expects an attention shift to a nearby object to occur after initial target detection. That is, the subsequent engagement would highly likely to be task relevant object. Thus, it predicts larger interference for distractor at the relevant stimulus array compared to that of the irrelevant array.

Experiment 1

Experiment 1 aimed to examine whether the number of irrelevant conflicting distractors modulates the amount of distractor interference when perceptual load is high. Participants were to perform the visual search task, which was identical to Lavie and Cox's (1997) experiments. However, unlike the original experiments that contained only one conflicting distractor, one, two, or four different conflicting distractors appeared in four possible peripheral locations. According to the perceptual load theory, no congruency effect should be obtained regardless of the number of the conflicting distractors, because the perceptual load theory assumes that all irrelevant stimuli are pre-attentively filtered out when those are physically distinguished from relevant stimuli when perceptual load is high. Thus, the irrelevant conflicting distractors would not be expected to disturb the target processing. However, because a chance that one of peripheral conflicting distractors captures attention increases as the number of them increases, the attentional capture account expects that the amount of interference would increase with the number of the conflicting distractors.

Method

Participants Eighteen undergraduate students at Korea University participated for partial fulfillment of a course requirement or monetary reward (5,000KRW). All of them had normal or corrected-to-normal visual acuity. The present and following experiments were approved by the Institutional Review Board at Korea University.

Apparatus Matlab and Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) were used to program the experiment. Stimuli were presented on a 17 inch CRT monitor of an IBM-compatible microcomputer with viewing distance of approximately 60 cm. Manual responses were collected from the "j" and "f" keys of a standard computer keyboard. The experiment was conducted in a light and sound attenuated chamber.

Design Participants were instructed to press the "f" key with the left index finger when the target was one of letters from A, B, C, D, and E or the "j" key with the right index finger when the target was one of V, W, X, Y, and Z. The mapping was counterbalanced across participants. All participants completed 12-practice trials and five blocks of 120-trials. One-minute break was given between the blocks. Overall Experiment took approximately 50 min.

Stimuli and Procedure All stimuli were presented on a black background colored in white. Multiple numbers of letters were designated as targets to avoid perceptual overlap among the letters. The first and last five consecutive English alphabet letters were selected as targets in order to reduce the excessive memory load. Thus, target letters were A, B, C, D, and E or V, W, X, Y, and Z (Arial, 0.5° x 0.8°). Also, J, K, L, M and N were used as

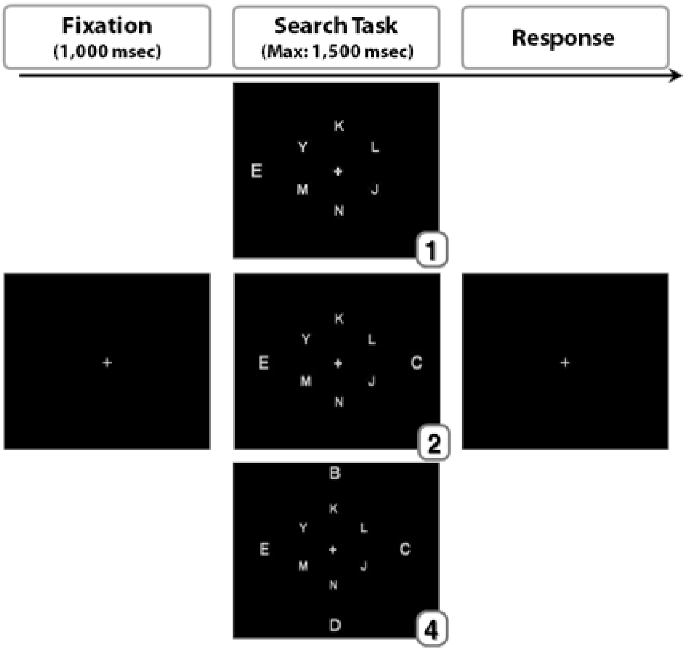

Figure 1. Examples of display in Experiment 1. The number (1, 2, and 4) in the rounded box indicates the number of conflicting letter. A target was presented at one of six positions in a central circular array with five neutral letters.

neutral letters. Figure 1 shows a sample display of Experiment 1. Participants were asked to press the 'f' key when the target letter, A, B, C, D, or E was presented and the 'j' key when the target letter, V, W, X, Y, or Z was presented. Each trial began with a fixation point "+" (0.6° x 0.6°) that presented at the center of display for 1,000 msec. The target display was presented for 1,500 msec, and it was replaced with the fixation point display until response was made. In a search array, a target letter was presented in one of the six positions with five different neutral letters in the others. Those letters were presented on an imaginary circle of with radius of 2°. One, two, or four task-irrelevant congruent or incongruent distractors (Arial, 0.6° x 1.0°) were presented on the up, down, left or right positions of the task-relevant stimulus array which were 4° away from the center. For example, when one of A, B, C, D, and E was presented as a target, incongruent distractors were randomly selected from V, W, X, Y, and Z without overlap. In the trials including two conflicting distractors, the distractors appeared in either up-down or left-right positions. All different uppercase letters were used in each trial. Auditory feedback (150-msec, 1,000-Hz) was given for incorrect responses or the late responses (>3.5 sec; see Figure 1). After 500 msec, the next trial began.

Results

Reaction times (RTs) faster than 150 msec and slower than 1,500 msec were excluded from data analysis as outliers (2.6% of the total trials). Mean RT and percent error (PE) were calculated for each participant as a function of the number of distractor (one, two, and four) and congruency (congruent and incongruent). Those variables were also compared between the location of distractors when the number of distractor was one (up, down, right and left) and two (up-down and left-right). Analyses of variance (ANOVAs) were conducted on the RT and PE data, with those factors as within-subject variables (see Table 1).

RT The main effect of congruency was significant, F (1, 17) = 28.86, $p < .0001$, MSe = 8,660, η_p^2 = 0.63. The mean RTs were shorter for congruent trials (M = 673 msec) than incongruent trials (M = 691 msec), indicating a 17-msec flanker compatibility effect. The main effect of the number of distractor indicated that the overall RTs increased as the number of distractor increased, F (2, 17) = 21.53, $p < .0001$, MSe =3,257, η_p^2 = 0.56. Importantly, the interaction of congruency and number of distractor was significant, F (2, 17) = 3.7, $p < .05$, MSe =741, η_p^2 = 0.19. The magnitude of the congruency effect was 11

Table 1. Mean Reaction Time (in milliseconds) and Percentage of Error in Experiment 1 as a function of the number of conflicting letter and congruency.

		The number of conflicting letter		
		One	Two	Four
Congruent	RT	666	677	676
	PE	5.2	5.1	5.3
Incongruent	RT	677	691	704
	PE	4.8	5.4	4.5
I - C	RT	11*	15**	28***
	PE	-0.4	0.4	-0.9

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

msec, F (1, 17) = 3.72, p = .07, MSe = 1,078, η_p^2 = 0.18, with one distractor, 15 msec, F (1, 17) = 8.98, p = .01, MSe = 1,922, η_p^2 = 0.35, with two distractors, and 28 msec, F (1, 17) = 36.18, $p < .0001$, MSe = 7,143, η_p^2 = 0.63, with four distractors (Figure 2). Pairwise comparisons revealed that the interaction of congruency and number of distractor was only evident between two and four distractors, F (1, 17) = 5.34, $p < .05$,

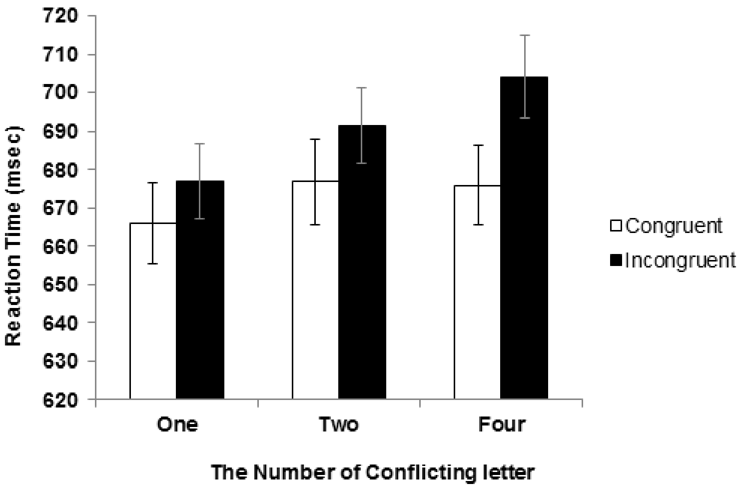

Figure 2. Mean RTs as a function of the number of conflicting letter and Congruency in Experiment 1. Error bar indicates within-subject standard error.

$MSe = 827$, $\eta_p^2 = 0.24$.

PE The overall PE was 5.05%. The statistical analysis revealed no significant main effect or interaction.

Discussion

When there was one distracting letter at peripheral area, the congruency effect (11 msec) was not significant. However, it increased up to 28 msec which was statistically significant when the number of distractor increased to two. This result is inconsistent with the perceptual load theory's prediction that physically distinguished (*e.g.,* location, size, or color) irrelevant stimuli are filtered out in the pre-attentive visual processing stage under high load. Unlike the previous study showing a null interference effect under high perceptual load (e.g., Lavie, 1995), a marginally significant congruency effect was obtained with one conflicting distractor even though perceptual load was high in Experiment 1. Two possibilities could be suggested for explaining this discrepancy. First, presenting a single or multiple distracting letters in random locations among the four possible peripheral locations might have captured attention, as an abrupt onset cue captures attention. In this case, it is highly likely to occur that attention was shifted to one of suddenly pop-out stimuli appearing at periphery. The second possibility is that the physical distinction between the relevant and irrelevant stimuli has not successfully carried out. Especially, high the complexity of the display in the trials to which involved four distractors might have resulted in vague discrimination of the relevant and irrelevant items. In this case, it is possible that failure of filtering in the pre-attentive stage resulted in a reliable interference effect in Experiment 1.

Experiment 2

In Experiment 2, two characteristics of the irrelevant stimuli were manipulated. First, four different irrelevant letters were presented in every trial including one or two conflicting distractors along with neutral letters. Presenting a fixed number of irrelevant letters was expected to eliminate the possibility that the conflicting distractors can be an abrupt onset item. Second, irrelevant letters were differentiated by color to clearly discriminate those from the task-relevant ones. By doing so, the relevant and irrelevant stimuli were clearly segregated by both of its color and location. According to the perceptual load theory, the extent of which an irrelevant distractor is processed should be equivalent regardless of the number of the conflicting distractors, resulting in no congruency effect. However, the probability that a conflict distractor captures attention is high when more distractors are included in a given display. Also, more features could be extracted from conflicting distractors at earlier visual processing stage when the more conflicting items take place in display. In the both cases, the size of interference effect would be larger when two conflicting distractors were presented than when one conflicting distractor was presented.

Method

Participants Thirty-two undergraduate students at Korea University participated for partial fulfillment of a course requirement or monetary reward (5,000 KRW). All of them had normal or corrected-to-normal visual acuity.

Apparatus It was identical to that of Experiment 1.

Design Participants were instructed to press the “f” key with the left index finger when the target was one of letters from M, N, and L or the “j” key with the right index finger when the target was one of V, W, and X. The mapping was counterbalanced across participants. There were two practice-blocks of 12 trials before starting the test-trial block. In the first practice block, the target was colored in pink to make the participants being familiar with the search task. The second practice block was followed after the participants answered that they fully understood the task instructions. It consisted of four 120-trial test blocks. A 1-min rest period was given after completion of each test block.

Stimuli and Procedure The task stimuli and procedure were identical to those of Experiment 1 with few exceptions. Each trial began with a fixation point “+” (0.6° x 0.6°) presented at the center of display for 1,000 msec. Then, the target display appeared for 1,000 msec followed by the blank screen for 1,000 msec while no response was recorded. The target letters was one of M, N and L or V, W and X (Arial, 0.5° x 0.8°), and the neutral letters were selected from R, H, S, T, Q, P, J and K. Figure 3 shows a sample display of Experiment 2. Similar to Experiment 1, six different letters were presented on an imaginary circle which was 1.4° of radius from the center (center to center). Every trial had four different irrelevant letters (Arial, 0.7° x 1.1°) which were presented on the vertex of an imaginary square surrounding the task-relevant stimulus circular array (2.2° from the center). One or two of the irrelevant letters were conflicting distractors with three or two neutral letters. When the number of the conflicting distractor was two, each distractor was always presented at both left and

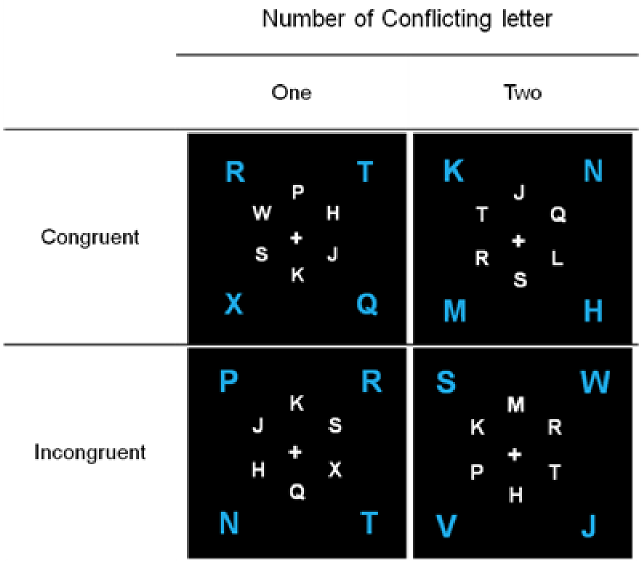

Figure 3. Sample displays in Experiment 2. The participants were required to press the left or right button according to whether a targeted letter (on the central array) was one among M, N and, L or V, W and X respectively.

right visual field. Thus, those distractors were diagonally (upper-left and lower-right or lower-left and upper-right) located among the four irrelevant letters. Moreover, the irrelevant letters were colored in sky-blue (R: 30, G: 170, B: 230) in order to make a clear distinction between the task relevant and irrelevant items. The positions of the target and distractor were fully counterbalanced within a participant. Auditory feedback (150-msec, 22 kHz) was given for incorrect responses or no-response. After the 500 msec, the next trial began.

Results

RTs shorter than 150 msec and longer than 1,500 msec were excluded from data analysis as outliers, with 7% of the trials removed. Mean RT and PE were calculated for each participant as a function of number of distractor (one and two) and congruency (congruent and incongruent). Those variables were also compared between the location of distractors when the number of distractor was one (up, down, left and right) and two (upper-left/lower-right and upper-right/lower-left). ANOVAs were conducted on the RT and PE data, with those variables as within-participant variables (see Table 2).

Table 2. Mean Reaction Time (in milliseconds) and Percentage of Error in Experiment 2 as a function of the number of conflicting letter and congruency

		The number of conflicting letter	
		One	Two
Congruent	RT	852	846
	PE	2.9	3.6
Incongruent	RT	852	858
	PE	3.6	3.1
I - C	RT	1	13*
	PE	-0.2	-0.6

Note. *p < .05.

RT The main effect of congruency was significant, F (1, 31) = 4.88, $p < .05$, MSe =5,946, η_p^2 = 0.14. However, the main effect of the number of distractor was not significant, $p > .9$. A significant interaction effect was obtained between congruency and number of distractor, F (1, 31) = 5.43, $p < .05$, MSe =4,614, η_p^2 = 0.15. The congruency effect was 1 msec when one distractor was presented as a task-irrelevant letters and it increased to 13

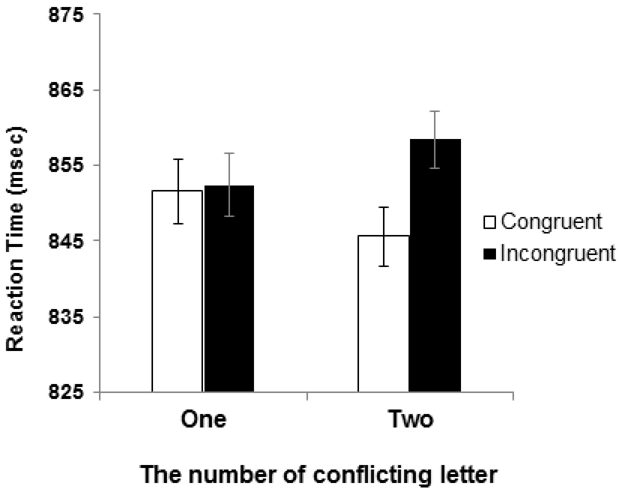

Figure 4. Mean RTs as a function of the number of conflicting letter and Congruency in Experiment 2. Error bar indicates within-subject standard error.

msec when two distractors were (Figure 4). Simple main effect analyses revealed that the size of the congruency effect was only significant with two distractors, F (1, 31) = 12.6, p < .01, MSe =10,518, η_p^2 = 0.29.

PE The overall PE was 2.8%. The main effect of congruency was not significant, F (1, 31) = 1.51, p = .23, MSe =19, η_p^2 = 0.05. The participants permitted more errors with two distractors (3.4%) than one distractor (2.8%), F (1, 31) = 4.41, p < .05, MSe =35, η_p^2 = 0.12. However, the interaction of congruency and number of distractor was not significant, F (1, 31) < 1.0. No substantial amount of interference effect was found in other variables.

Discussion

In Experiment 2, in which the numbers of the task-relevant letters and task-irrelevant letters were constant and the physical difference between the task-relevant and irrelevant letters was clear, no distractor interference was observed when one conflicting distractor was presented. This null-interference was consistent with perceptual load theory's prediction. However, a meaningful distractor interference effect was found when two conflicting distractors were presented as task-irrelevant letters. According to Lavie and Cox's (1997) perceptual load theory, irrelevant stimuli should have been pre-attentively filtered out under the high perceptual load, resulting in no interference effect regardless of the number of the conflicting distractor. As in Experiment 1, the findings in Experiment 2 did not support the perceptual load theory. Given the fact that Experiment 2 preliminarily eliminated any possibility of stimulus-based attentional capture by irrelevant letters, it is more obvious in Experiment 2 that the increased amount of congruency effect could be attributed to either attentional shift toward distractor or enhanced feature representation of distractor result of increased proportion of distractors.

Experiment 3

Lavie and Torralbo (2010) suggested that reduced distractor interference under high dilution display is attributed to 'attentional spillover' to neutral letters rather than feature dilution as early-visual interference view suggested. In their experiment, participants were asked to identify a target on a circular array of six letters while ignore peripherally presented distractor. Similar to the Benoni and Tsal's (2010) dilution paradigm, a target was colored in green but a conflicting distractor was located at either target-array or periphery. They suggested that, in the perspective of the early-visual interference view, the amount of early visual crosstalk should have been equivalent irrespective to the distractor position. Hence, the result has shown that the congruency effect was larger when the conflicting distractor was located at the target-array than when it was located at periphery that was inconsistent to dilution account. Based upon this finding, they concluded that, subsequent to target perception, remaining attentional resource would spillover to non-target letters on the target-array (e.g., letters on the circular target array) not to peripheral distractor under low perceptual load.

However, it is possible that the peripherally presented distractors (i.e., 3.5° from fixation) have activated visual representation not as much as that of the centrally located distractors due to reduced visual acuity projected to retina at peripheral visual field (Brown, et al., 1995). In order to maintain the constant visual acuity, Experiment 3 has reduced radius of target and distractor arrays of Benoni and Tsal's (2010) Experiment 1b. In their experiment, a colored target (e.g., red or green) letter was presented with four irrelevant letters including three central non-target items and one peripheral distractor. As in Lavie and Torralbo's (2010) experiment, a conflicting distractor was presented at one of the target array or a task-irrelevant peripheral location. Also, the number of conflicting distractor was manipulated to examine what extent an additional conflicting distractor would interrupt target processing.

The early-visual interference account suggests that the simple presence of the conflicting stimulus is sufficient to make perceptual crosstalk at the feature extraction stage. Considering the fact that the distance between the peripheral letter and fixation was reduced, the amount of the congruency effect should be equivalent regardless of its position when the ratio of conflicting distractor and the display size are constant. If, however, the nature of irrelevant processing depends on whether a conflicting distractor captures attention, a distractor presented at the central array would cause a larger amount of distractor interference than a peripherally presented conflicting distractor would. When two conflicting distractor were presented, according to the attenional capture account, because the probability of attentional capture by a conflicting letter increased, resulting in a large congruency effect. Early-visual interference account also expects the same result by much features from conflicting letter would be extracted when there are two conflicting distractors than a single distractor.

Method

Participants Thirty-two undergraduate students at Korea University participated for partial fulfillment of a course requirement or monetary reward (5,000 KRW). All of them had normal or corrected-to-normal visual acuity.

Apparatus It was identical to the previous experiments.

Design Participants were asked to press the "f" key on the keyboard with left index finger when the target was one of C, S, or Q and "j" key on the keyboard with right index finger when the target was one of H, K, or F. There were catch trials that took 10% of the overall trials. In those trials, one of the neutral letters, which was randomly selected, was colored in red. Thus, the participants had to withhold their response for those trials. The catch trials were inserted to prevent participants' strategies, such as target identification based on the feature (e.g., curve *vs.* straight line). The response mapping was counterbalanced across the participants. The participants were required to focus the red stimulus on the display while avoiding excessive eye movement. A practice block consisting of 16 trials were preceded. The participants completed 5 blocks of 190 trials. One-minute break was given between each block. The running time of Experiment was about 50 minutes.

Stimuli and Procedure Sample display of Experiment 3 was provided in Figure 5. The properties of stimuli were identical to Benoni and Tsal's (2010) Experiment 1b with few exceptions. Each trial began with the fixation point that was a small dot subtended 0.1° in width and height. The fixation point was presented at center for 500 msec followed by 500 msec blank screen. Then, the target display appeared until response was made. The target letter was one of C, S, and Q or H, K, and F

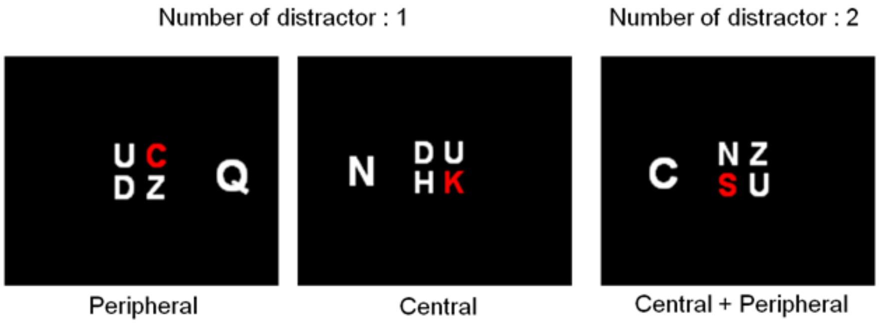

Figure 5. Examples of display in Experiment 3. A target was always colored in "red" while others remained "white". The participants were requested to press the left or right button according to whether target was one of C, S and Q or H, K and F.

and neutral letters were D, N, U, and Z (Arial, 0.4° x 0.4°). The target and neutral letters were presented in four vertex of imaginary square subtended 0.4° from the center of the screen. The target letter was always colored in red (R: 255, G: 0, B: 0), while others were white (R: 255, G: 255, B: 255). There were three types of trials depending on the location of distractor; peripheral, central, and combined. In one type of trials, a distractor or neutral letter subtended 0.5° in width and 0.7° in height was presented in either left or right to the central search array. The distance between the center of the screen and the peripheral letter was 1.5°. In another type of trials, a conflicting distractor appeared in one of the four positions in the central search array, while a neutral letter at one of the peripheral positions. To distinguish the target from the conflicting distractor, the distractor was colored in white like other neutral letters. The two different distractors were simultaneously presented at central array and peripheral area in the other types of trials. Auditory feedback (150-msec, 22 kHz) was given for incorrect responses. ITI was 500 msec.

Results

RTs deviating by two SDs from the mean were excluded from data analysis as outliers, with 2.5% of the trials removed. Mean RT and PE were calculated for each participant as a function of the types of distractor position (peripheral, central, combined) and distractor congruency (congruent, incongruent). ANOVAs were conducted on the RT and PE data, with

Table 3. Mean Reaction Time (in milliseconds) and Percentage of Error in Experiment 3 as a function of the number of conflicting letter, position of conflicting letter and congruency.

		The number of conflicting letter		
		One		Two
		Peripheral	Central	Peripheral + Central
Congruent	RT	648	643	639
	PE	2.8	2.2	1.7
Incongruent	RT	649	653	655
	PE	2.3	3.1	2.8
I - C	RT	1	10**	16***
	PE	-0.5	0.9**	1.1**

Note. ***p* < .01. ****p* < .001.

those variables as within-participant variables (see Table 3).

RT The main effect of congruency was significant, $F\ (1,\ 31) = 12.83$, $p < .01$, $MSe = 1{,}520$, $\eta_p^2 = 0.29$. Also, the interaction of distractor location and congruency was significant, $F\ (2,\ 31) = 5.57$, $p < .01$, $MSe = 806$, $\eta_p^2 = 0.15$. The size of the congruency effect for peripheral, central, and combined locations was 1 msec, 10 msec, and 16 msec, respectively (Figure 6). Further analysis on the simple effect indicated a meaningful effect size in central, $F\ (1,\ 31) = 8.47$, $p < .01$, $MSe = 989$, $\eta_p^2 = 0.21$, and combined locations, $F\ (1,\ 31) = 18.48$, $p < .001$, $MSe = 1{,}084$, $\eta_p^2 = 0.37$, but not for the distractor on peripheral location, $F\ (1,\ 31) < 1.0$. In separate analyses, the two-way interaction of congruency and distractor location for peripheral and central types was significant, $F\ (1,\ 31) = 4.1$, $p = .05$, $MSe = 834$, $\eta_p^2 = 0.12$. On the other hand, the two-way interaction of congruency and central and combined location was not significant, $F\ (1,\ 31) = 2.02$, $p = .17$, $MSe = 619$, $\eta_p^2 = 0.17$.

PE The overall PE was 2.5%. The main effect of congruency was significant, $F\ (1,\ 31) = 5.63$, $p < .05$, $MSe = 11$, $\eta_p^2 = 0.15$. Also, the interaction of distractor location and congruency showed significant, $F\ (2,\ 31) = 9.63$, $p < .001$, $MSe = 7$, $\eta_p^2 = 0.24$. The size of the congruency effects for peripheral, central, and combined locations were -0.5%, 0.9%, and 1.1%, respectively. Further analysis on the

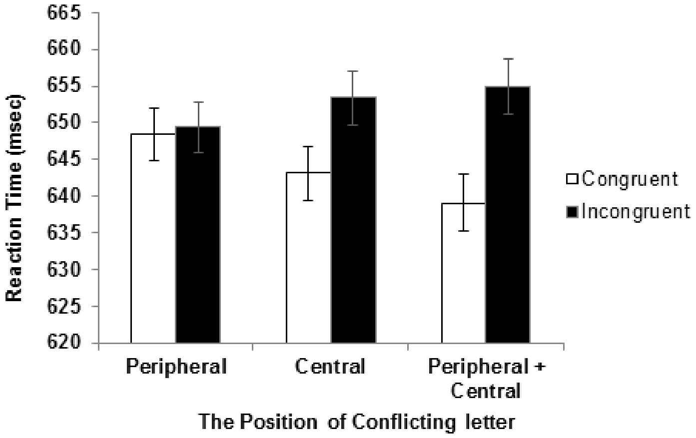

Figure 6. Mean RTs as a function of the position of conflicting letter and Congruency in Experiment 3. Error bar indicates within-subject standard error.

simple effect indicated a significant effect size in the central, $F\ (1,\ 31) = 8.1,\ p < .01,\ MSe = 9,\ \eta_p^2 = 0.21$, and combined types of trials, $F\ (1,\ 31) = 12.24,\ p < .01,\ MSe = 9,\ \eta_p^2 = 0.28$, but not for the distractor at the peripheral location, $F\ (1,\ 31) = 2.73,\ p > .1,\ MSe = 8,\ \eta_p^2 = 0.08$. The interaction of congruency and distractor location for peripheral and central types was significant, $F\ (1,\ 31) = 17.26,\ p < .0001,\ MSe = 5,\ \eta_p^2 = 0.36$. On the other hand, the same analysis on the central and combined types was not significant, $F\ (1,\ 31) < 1.0$.

Discussion

Consistent with Lavie and Torralbo (2010), the congruency effect was significant only when a conflicting distractor was presented on the relevant target array. In particular, the congruency effect was 1 msec with one peripheral distractor, but it increased to 10 msec with one central distractor and 16 msec with two distractors at central and peripheral locations.

Tsal and Benoni's (2010) dilution account expects that the amount of degrade in feature representation should be same irrespective to the position of conflicting distractor when the ratio of the number of the conflicting distractor to the display size was constant. However, consistent with the expectation of the attentional capture account, a distractor located on the target array produced a larger interference effect compare to that of peripheral one. The result suggests that the distractor nearby the currently focused area had attentional priority. In addition, although the congruency effect was slightly larger when two distractors were presented at central and peripheral positions each than when a distractor was presented at central position, this difference was not statistically significant ($p = .06$).

General Discussion

In three experiments, in which the number (Experiments 1, 2, & 3) and the position (Experiment 3) of the irrelevant conflicting distractors were manipulated, the nature of selective attention under the high perceptual load was examined. The magnitude of the congruency effect from a peripheral distracting letter increased as the number of the distracting letters in the display increased in Experiment 1: 11-msec, 15-msec, and 28-msec congruency effects with one, two, and four distracting letters, respectively. This positive relationship between the amount of interference and the number of the conflicting letter was consistently observed even when the physical distinction between the irrelevant and relevant stimuli was further reinforced by the use of different colors in Experiment 2. These findings were obviously inconsistent with the perceptual load theory's assumption on the earlier visual filtering of irrelevant information under high load display (Lavie & Tsal, 1994). Furthermore, the linear relationship of the congruency effect with the number of the distracting letter found in Experiments 1 and 2 suggests that the probability of attentional capture by a distracting letter indeed determines the visual processing in high perceptual load. If dilution occurs because of perceptual crosstalk among the features of the task-irrelevant letters, as Tsal and Benoni (2011) suggested, an equivalent amount of dilution should have been obtained regardless of the location of the irrelevant conflicting letter. However, in Experiment 3, which aimed to investigate the source of dilution, the congruency effect was larger when the conflicting letter was presented at a location nearby the target than at a peripheral distracting letter on the dilution display. The result is consistent with the attentional capture account's prediction that attention shift to a nearby letter easier than a distant letter after initial target detection.

The possibility of early-visual crosstalk

The early-visual interference account could provide an alternative explanation for the results of Experiments 1 and 2, which showed that the congruency effect increased as a function of the number of task-irrelevant conflicting distractors. It has been suggested that the object detection does not follow an all-or-none fashion, but a briefly presented object can activate a part of feature representations which are necessary for response selection (Estes, 1972; Shiffrin & Gardner, 1972; Shiffrin & Geisler, 1973). Based on this assumption, the *coactivation model* (Miller, 1982) suggested that the activation from multiple sources is combined to some extent until it reaches to the threshold for response initiation. Although an object is not enough to elicit semantic interpretation, more than two redundant objects can successfully bring about response initiation by pooling the activations from each object. Such as the more pieces of puzzle serve the more accurate estimation about the whole picture, this model suggests that activations from multiple conflicting distractors were combined to some extent which was enough to elicit the congruency effect in Experiments 1 and 2. However, in Experiment 3, the magnitude of distractor interference was evident only when the distractor was located nearby the target array. This result is inconsistent with the early-visual interference view's prediction that an equivalent amount of distractor interference should occur regardless of its location in the display. Because, basically, the account assumes that when the ratio of the number of the distractor to the number of the neutral objects is fixed, the amount of activated feature representation which is needed for processing the meaning of distractor would be constant resulting in the equivalent distractor interference in the semantic stage. In regard of the null interference with a peripheral conflicting distractor obtained in Experiment 3, according to Brown, et al.'s (1995) view, the amount of early-visual crosstalk at peripheral visual field have no choice but smaller than that of central area due to the difference in the visual acuity. However, considering the fact that Experiment 3 maintained the overall visual acuity by reducing the distance between peripheral letters to fixation (less than 1.5°), these outcomes could not be attributed to the weakened visual acuity at peripheral visual field.

Attentional spillover hypothesis

Lavie and Torralbo (2010) proposed the 'spillover hypothesis' to explain the Tsal and Benoni's (2010) dilution phenomenon in terms of the perceptual load theory. They argued that once a target is identified under low perceptual load, attention spills over to a nearby object when there is residual attentional resource. They interpreted the reduced congruency effect under dilution display in Tsal and Benoni's experiment as a result of attention spillover to neutral letters which located in the relevant stimulus array not the peripheral distractor. However, as Tsal and Benoni (2010b) pointed out, the 'spillover hypothesis' contradicts the perceptual load theory itself with respect to its key notion that it has initially stood by. The main idea of the perceptual load theory, which claimed the perceptual load as a key determinant for the locus of selection, does not imply any possibility of 'spillover' in low perceptual load. That is, the term 'spillover' contradicts the perceptual load theory's assumption of parallel visual processing under low perceptual load.

Furthermore, the significant interference effects under high perceptual load observed in the present study are inconsistent with the spillover hypothesis which assumed that the spillover occurs when there is enough available attentional resource. The outcomes of the present study indicate that a distractor can be processed up to some extent regardless of the amount of resource which is needed for successful target processing. For example, significant distractor interference was repeatedly observed under high perceptual load in Experiments 1 and 2. Thus, the term 'spillover' does not seem suitable for rationalizing the present result. Rather than, it is suggested that, as a generalized term, 'attentional capture by a distractor' determines the distractor interference effect irrespective to the types of load.

Evidences of Attentional-capture in the present study

In Experiment 3, the congruency effect was larger when a conflicting distractor was located nearby the target than when the distractor was located at peripherally remote location. Despite two conflicting distractors presented at both of the target array and peripheral location produced a slightly larger congruency effect (16 msec) than a single distractor located nearby the target did (10 msec), this difference did not show statistical significance. It suggests one possibility that, if a conflicting distractor located nearby the currently focused region captures attention, then an additional distractor positioned at relatively far from the current focus would not be processed. Consistent with this result, Kahneman and Chajczyk (1983) reported that the additional presentation of an incongruent color word had no impact on the size of the Stroop effect compared to the effect with one color word. MacLeod and Hodder (1998) also found a similar phenomenon and explained it as, “the first word captures attention and it ‘locks out’ subsequent captures inhibiting the further distractor interference” (p.212; see also Yantis, 1993).

Further evidence of selective processing of the irrelevant distractor was reported by Marciano and Yeshurun (2011). They suggested that spatial uncertainty of the distractor plays an important role in determining the attentional selection under load induced display. Their experiments adopted the paradigm of Lavie and Cox (1997), in which a conflicting distractor was presented at one of two peripheral locations, with an exception that a conflicting distractor was presented at one of ten peripheral locations comprising a circular array. Interestingly, a significant congruency effect was found under high perceptual load. They attributed the processing of the conflicting distractor to that uncertainty of the distractor location made participants hard to ignore task-irrelevant stimuli successfully. In line with Marciano and Yeshurun, a peripheral distractor produced marginally significant distractor interference (11 msec) when the distractor was presented one of four peripheral locations in Experiment 1. In Experiment 2, however, a significant congruency effect was obtained under high perceptual load even though the number and location of the irrelevant letter was fixed. It suggests that the spatial uncertainty of the distractor alone could not serve the plausible answer for the present results.

In addition, the display duration should be noted in the most perceptual load studies used a brief display duration (less than 150msec) whereas it was relatively long in the present study (until response). The longer the display presentation the probability of the attentional capture by irrelevant distractor increases. As mentioned earlier, Kim et al. (2008) demonstrated that, in a separated Stroop paradigm, a longer display presentation resulted in a larger Stroop effect by increasing the chance of the conflicting color word capturing attention. In this notion, it can be interpreted that the short display duration in the previous studies indeed did not permit the participants to shift their focus of attention from the target to a distractor under high perceptual load. On the other hand, such distractor processing was possible even with a 150-msec display presentation under low perceptual load, producing a remarkable distractor interference effect.

Apparently, the findings that manipulations on the chance of attentional capture, such as the number of distractor, visual saliency, spatial uncertainty, or the display duration, influenced the extent of distractor processing regardless of the perceptual load support the view of the attentional capture account.

Active role of selective attention

As described earlier, bottom-up attentional capture has been reported in a way that a salient distractor could produce distractor interference even under high perceptual load (Cosman & Vecera, 2010; Eltiti, Wallace, & Fox, 2005; He & Chen, 2010; Sand & Weins, 2011). Some studies, however, also suggested top-down attentional setting overrides the perceptual load in a specific context (Benoni, Zivony, & Tsal, 2014). Theeuwes, Kramer, and Belopolsky (2004) suggested that attentional set influences the efficiency of visual processing. They tested the perceptual load theory using the same display of Lavie and Cox (1997) in separated block (Experiment 1) and mixed block (Experiment 2) procedures. The result of Experiment 1 followed the prediction of the perceptual load theory. However, in Experiment 2, an evident congruency effect was found under high perceptual load when the previous trial was low perceptual load. According to them, because the participants broadened their attentional window when they experienced the low perceptual load, the target processing was disrupted from the irrelevant distractor in the following high load trial.

Nevertheless, Theeuwes et al.'s (2004) findings do not precisely indicate whether the result was based on participants' active modulation of the attentional window or the passive influence from the trace of the previous processing which remained until the subsequent trial. Regarding this issue, Biggs and Gibson (2010) advocated the active role of top-down control dominating the perceptual load. They tested whether color-saliency distractor captures attention under the control of perceptual load. In their Experiment 2, an evident distractor interference effect was observed under high perceptual load when the advance knowledge of the types of load and the color of the distractor were available. Given the fact that the level of perceptual load was fixed within the block, their result could be attributed to the top-down control of distractor processing. Recently, Roper, Cosman and Vecera (2013) demonstrated that variables influencing visual search efficiency (e.g., target-distractor similarity and distractor-distractor similarity) corresponded with perceptual load. They suggested that attention spilled over to a conflict flanker, resulting in a congruency effect only for the trials of low target-distractor similarity which usually have shown an efficient visual search slope (see also Chen & Cave, 2012). Overall findings bring an important notion that the perceptual load phenomenon is not a resource dependent passive mechanism as the perceptual load theory suggested, but an active control mechanism of attentional allocation which seems to determine the extent of distractor processing under complex visual display.

Conclusion

This study addressed two major conclusions: First, the perceptual load is not be the key factor to determine the extent of visual processing. Second, the perceptual load phenomenon is possibly due to the result of dilution at the focused attention stage not due to the visual crosstalk at the pre-attentive stage. The present study provides an important insight into increasing the perceptual load indeed decreases the probability of attentional capture by a distractor, resulting in a reduced congruency effect. In addition, the overall results indicate that when the distractor had a higher probability of attentional capture it dominated the perceptual load. Thus, the amount of perceptual load does not matter but various factors of which potentially influencing the chance of attentional capture seems to determine the extent of distractor processing. More research should be needed to illuminate the role of attentional capture under complex visual display.

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지각부하 이론과 초기 시각 혼선 이론의 대안으로서의 주의 획득

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과제와 관련이 없는 정보의 처리가 제시된 과제 관련 자극 집합의 크기가 증가함에 따라 감소하는 현상을 설명하기 위해 지각부하 이론(Lavie & Tsal, 1994)과 희석 이론(Tsal & Benoni, 2010)이 제안되었다. 본 연구의 목적은 과제 비관련 정보 처리에 미치는 자극 집합 크기 효과의 본질을 알아보고자 하였다. 본 연구에서는 한 개의 방해 자극이 있는 높은 지각부하 조건에서 합치효과가 나타나지 않았다. 하지만, 방해자극의 숫자나 비율이 증가함에 따라 합치효과도 함께 증가하였다(실험 1과 2). 희석 조건(실험 3)에서는, 이전 연구 결과와 같이, 방해자극이 과제 비관련 주변 위치에 제시되었을 때 보다 과제 관련 자극 배열에 제시되었을 때 더 큰 합치효과를 발견하였다. 하지만, 두 개의 방해자극을 함께 제시되었을 때에는 합치효과의 크기는 한 개의 방해자극이 제시되었을 때와 다르지 않았다. 이러한 결과는 과제 관련 자극의 수가 증가함에 따라 나타나는 지각 부하 효과가 방해자극이 주의를 획득하는 확률이 감소함에 따라 나타나는 현상으로 보인다. 또한, 본 연구의 결과는 이러한 선택적 처리는 초기 시각 혼선으로 나타나기 보다는 초점 주의 단계에서 나타남을 보여주었다.

주제어 : 희석, 지각적 부하, 주의 획득, 갈등, 시각 혼선