주의에 의한 시각 공간 확장†

Attention-induced expansion in visual space

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요 약 특정 위치에 주어진 선택적 주의에 의해 발생하는 지각 변화를 수용장의 수평 이동 가설 및 시각 공간의 확장 가설을 통해 실험적으로 검증하였다. 검사 자극의 주위에 일정 형태로 배열된 점들의 일부를 깜박이거나 그 점들에 선택적으로 주의를 기울이도록 함으로써 외인적으로 또는 내인적으로 주의가 유도되었으며 지각 변화 정도는 동시에 제시되는 검사 선분의 버니어 정렬, 기울기 및 길이 판단을 통해 측정되었다. 주의 효과는 상-하향 단계 조절법(up-and-down staircase method)을 사용하여 버니어 정렬 및 기울기 실험에서는 수직으로 배열된 것처럼 지각되는 검사 선분의 위치나 기울기로, 길이 판단 실험에서는 검사-비교 자극간의 주관적 등가점(PSE: point of subjective equality)으로 측정되었다. 내인적, 외인적 주의 조건 모두에서 수직선이 주의 착점에서 멀어지는 쪽으로 밀쳐 지각된다는 것과 그 부위에 가까이 제시된 선분이 길게 지각된다는 것이 발견되었다. 주의에 의한 이러한 지각 변화는 검사 자극이 주의 착점으로부터 멀어질수록, 주의 유도후 검사 자극 제시까지의 시간이 길어질수록 감소하였다. 수직 선분 자극이 주의 착점으로부터 밀쳐져 지각되고 수평 선분이 주의 영역 부위에서 길게 지각된 실험 결과는 주의에 의한 지각 변화를 설명하는데 있어 수용장 이동 가설보다는 지각 공간 확장 가설이 더 적절함을 시사한다.

Abstract Selective attention induces perceptual distortions, ranging from repulsion of objects located near the attended area(Suzuki & Cavanagh, 1997) to magnification of the unattended objects(Tsal & Shalev, 1996). Two hypothetical mechanisms have been postulated: a shift of receptive fields' positions away from the locus of attention(receptive-field-recruitment hypothesis) or the enlargement of perceived space around the attended location(space-enlargement hypothesis). The present study distinguished between these hypotheses by investigating the spatial and temporal properties of attention-induced distortions. Perceptual judgements on vernier alignment, line tilt, line length were used to measure attention-induced changes in perception. Attention was induced exogenously(by blinking a specific set of dots around the test stimuli) or endogenously(by instructing the subject to selectively attend the dots). After inducing attention, the test stimuli were briefly flashed. A staircase method was used to measure the attentional effect. A vertical line was perceived as repelled from the locus of attention, and a line segment appeared longer when attention was given to its vicinity. The effects decreased as the distance between the locus of attention or the time between the onset of attention and the stimulus presentation increased. The results imply that the space-enlargement hypothesis provides a better explanation for the attention-induced changes in perception than the receptive-field-recruitment hypothesis.

Keywords attention, visual distortion, space enlargement

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1. Introduction

Human visual perception is biased to favour attended over unattended stimuli. From everyday life experience, we know that accuracy, speed or sensitivity of detecting or identifying an event increases when paying attention to this event.

Since Helmholtz(1896) devoted part of his work to these and related questions, a lot of models on visual attention have been developed to account for various aspects of attentional selectivity. Attention can be deployed willfully, and is then called "endogenous", "goal-directed", "top-down", or be summoned by the sudden occurrence of a perceptual event, and is then called "exogenous", "cue-induced" or "bottom-up"(Posner, 1980; Suzuki & Cavanagh, 1997). The exogenous attention has a sudden rise and a rapid decay, while the endogenous one has relatively slower fashion(Nakayama & Mackeben, 1989). Both forms of attention have limited spatial extent(Pan & Erikson, 1993; Henderson & Mcquistan, 1993).

It is not surprised that more interest has been devoted to the investigation of the temporal and spatial properties of attention than to its perceptual manifestation. Recently, however, a few works have shown that attention can speed up visual perception(Hikosaka, Miyauchi & Shimojo, 1993) and distort visual space(Suzuki & Cavanagh, 1997). Focused attention, be it exogenous or endogenous, causes briefly presented probes to be apparently repelled from the focus of attention. These findings were brought in connection with recent physiological findings. With a match-to-sample task, Moran and Desimone(1985) recorded cells' responses in the visual cortex V4 or IT of rhesus monkey and found that the cell's response dramatically changed, depending upon the locus of the animal's attention. They concluded that attention gates visual processing by filtering out irrelevant information from within the receptive field of cell in extrastriate cortex. In a follow-up study, Spitzer, Desimone and Moran(1998) found cells' responses in difficult task which requires more attentional effort were much stronger than the responses in easy task and their bandwidths were significantly narrower than in easy task. A similar attention-induced modulatory effects in V4 cells were also reported by Haenny and Schiller(1988). If V4 area is responsible for visual attention process, its ablation must be followed by predictable deficits in an animal's ability of stimulus selection. This is exactly what Schiller and Lee(1990). In their experiment the lesioned animal showed no deficit in detecting the presence of target, and mild deficit in discriminating brighter or larger target from the comparison stimuli. However, they showed great difficulties in discriminating dimmer or smaller target. Because the intense or large stimulus in the environment is likely to induce a reflex-like reaction while dimmer and smaller ones require a deliberately and sophisticately tuned reaction(Braun, 1994), the asymmetry in the discriminating abilities of lesioned animal can be taken as a strong indication that this area is strongly involving in visual attention process.

Although we do not fully understand the mechanism underlying the attention-induced changes in visual perception, these recent developments provide a new vantage point: If selective attention is able to change receptive field characteristics in the visual cortex, then perception of an object should also change, coinciding with the attention-induced changes in receptive field organization. Thus, depending on how much attention an object attracts, its visual field brightness, position or size could be distorted and, under some circumstances, even fail to reach the threshold of consciousness.

However, since we cannot observe attention as a process per se, psychophysical

investigations with human observers must concentrate on attention-induced changes in perceptual qualities. Enhancements in sensitivity, resolution, and speed of processing are well-known effects reported by existing studies. The sensitivity of detecting or discriminating a target increases when its location is cued, so that it may attract an observer's attention(Bashinski & Bacharach, 1980; Downing, 1988; Mueller & Rabbit, 1989). Likewise, cueing a position in the visual field yields enhancements in a position resolution of vernier acuity tasks(Nakayama & Mackeben, 1989). Attentional cueing also enhances the speed and accuracy of stimulus identification(Hikosaka, Miyauchi, & Shimojo, 1993).

Detailed descriptions on the attentional distortion relating the object's perceived position were reported by Suzuki & Cavanagh (1997). They found by using vernier-like stimuli that a vertical line was perceived as repelled away from the focus of attention. The repulsion effect occurred as attention was attracted automatically by a briefly flashed cue as well as by attending the cue voluntarily in a top-down process. The effect peaked at around SOA 200msec and declined as a function of cue-lead time, probe duration(peaks at around 100msec and falls off at longer durations). Suzuki and Cavanagh interpreted this phenomenon by postulating three hypotheses: 'surround suppression', 'receptive field recruitment', and 'receptive field shrinking'. Whatever the underlying hypothesis is, it puts forward to the shift of receptive fields for cells in V4 toward the focus of attention resulting in repelled perception of a vernier line away form the attentional focus(Connor, Gallant, & Van Essen, 1994).

Repulsion is just one aspect of attention-induced visual distortions. Chung & Yoo(1989) found that visual illusions can be induced by imagination. In an illusion-inducing paradigm they presented a certain configuration of dots forming the endpoints of the corresponding real illusion-inducing figures. After having mentally connected the dots in order to imagine the missing lines, the to-be-distorted probes were flashed. Chung and Yoo, finally, found that the same perceptual biases occurred as expected for the real illusory figures. For example in their Ponzo-like illusion stimulus, the horizontal line presented between the converging part of two imaginary diagonal lines, was perceived as larger than the identical line close to the diverging part. According to Suzuki and Cavanagh, the effect should have occurred in the opposite direction, because in order to mentally connect a specified configuration of dots the subjects had to direct attention synchronously to multiple locations and then the line close to the converging part was closer to two sources of attention. With these conflicting results, we suggested a space-enlargement hypothesis, guided by the idea of a relative magnification of space around the focus of attention, metaphorically speaking, a magnifying lens of selective attention.

The present experiments mainly aimed to investigate spatial and temporal influences of selective attention on visual perception, especially on distortions and illusions. By measuring attention-induced effects on the perception of vernier alignment, line tilt and line length of outlined figures we also intended to distinguish between the receptive-field-recruitment hypothesis and the space-enlargement hypothesis.

2. Experiment 1

In this experiment it was tested whether shift of attention(cue-induced or voluntarily-induced) causes perceptual displacement on briefly presented object. In line with previous finding(Suzuki & Cavanagh, 1997), we expected that a vertical line be perceived as repelled

away from the focus of attention. Additionally, spatial and temporal gradients of attention effect were examined by measuring perceptual displacements as functions of ISI and distance between cue and probe stimuli).

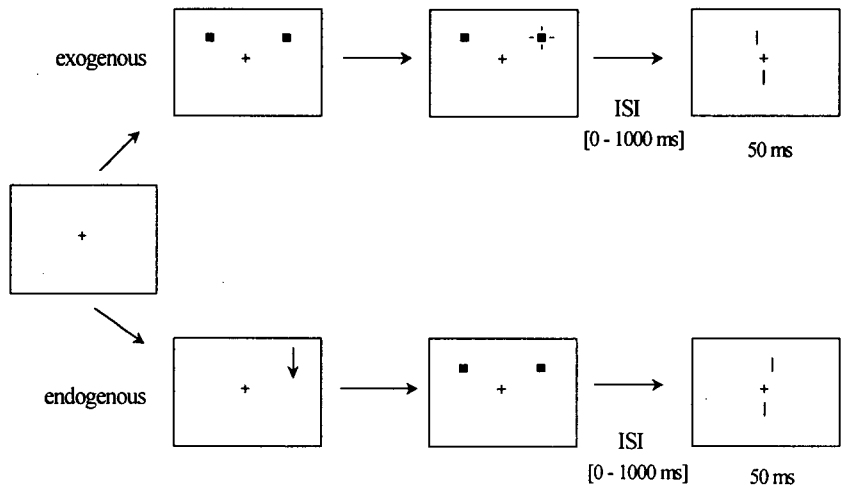
2.1 Method

Subjects. Two adult observers participated in Experiment 1. All observers were naive and had normal or corrected-to-normal vision.

Apparatus and Stimuli. The stimuli were presented on a 14-inch color monitor placed 75 cm from the subject. The resolution was 1024 x 768 pixels. To monitor the subject's response a keyboard was used. Overall procedure of the experiment was controlled by a 486 PC. All stimuli were white on a gray background. The observer's head movement was restrained by using a chin rest. The stimuli and procedure used in experiment 1 are illustrated in Figure 1.

segments. One of two dots(5′ of radius) on both sides of the upper probe stimulus are the attentional cue. In order to measure the spatial effects of attention, distance between cue and probe was varied as 30′, 50′ and 70′. For cue-induced attention effects, one of two inducing dots was blinked two times in order to automatically attract the observer's attention. In endogenous condition, the subject had to selectively attend to one of two dots previously indicated by an arrow to the left or right from the fixation cross.

Procedure. Each trial started with a fixation cross presented in the center of the monitor screen. Subject's fixation was maintained throughout the trial. Both exogenous and endogenous conditions have two subconditions, where the distance between the fixation cross and the inducing dots was varied(30′, 50′ and 70′) but the ISI was fixed at 50 msec, or the



(Fig. 1) stimulus configuration and the procedure of Experiment 1.

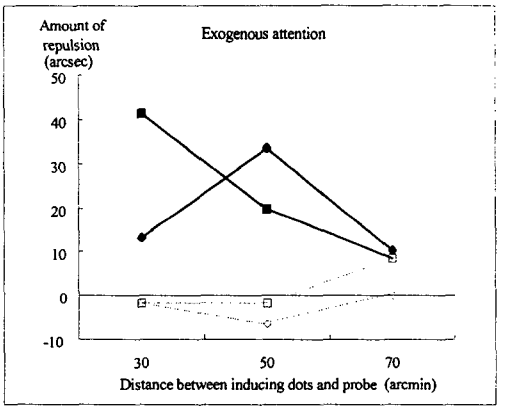
The vertical line segments above and below the fixation cross(40′ from the fixation cross) are the probe stimuli(1′ wide and 20′ long in visual angle). Effects were measured as the amount of vernier offset between these line

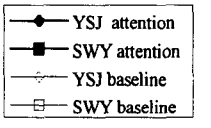
ISI was varied(0, 50, 100, 300 and 1000 msec) and the distance was fixed at 30′, respectively. In the exogenous condition, two small dots appeared for 400 msec to the upper left as well as to the upper right from fixation, whereby

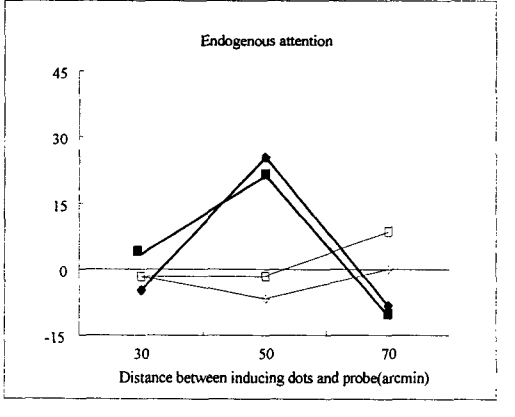
one of them started blinking to attract the observer's attention. After an ISI(either 50 msec or ranging from 0 - 1000 msec) the probe stimuli were flashed for 50 msec followed by a blank screen. An arrow was presented in endogenous condition for 300 msec to the left or to the right from the fixation cross as an indicator to which one of the following dots the subject should voluntarily direct attention. Having successfully shifted attention to the corresponding dot, he/she was to push a button. With an ISI (either 50 msec or ranging from 0 - 1000 msec) the probe stimuli were briefly flashed for 50 msec followed by a blank screen. At the end of trial the subject judged in a 2AFC(two alternative forced choice) manner whether the upper line segment appeared to the left or to the right from the lower one. The lower line segment was always located exactly below the fixation cross, whereas the position of the upper probe depended on the subject's response. In case the response indicated the repulsion effect, the location of the probe in the following trial would be shifted 1 pixel in the opposite direction, and vice versa. This staircase method was repeated until the response direction reached to 6 reversals to find the physical vernier offset considered as PSE(the point of subjective equality) between the locations of probes. The amount of effect for each block was calculated by averaging over the 3 upper and 3 lower extreme values, respectively. Exogenous/endogenous conditions as well as distance/ISI subconditions were tested separately. Each session with variable distances between attention-inducing dots and probe stimuli consisted of two exercise blocks followed by 18 experimental blocks, whereby the initial position of the upper probe line(1 pixel to the left, 1 pixel to the right or veridically aligned), the attention-inducing distances(30′, 50′ and 70′), and the direction of attention(left and right) were combined and presented in a random order. In the ISI condition, whole session consisted of 30 trials since it had five different ISIs(0, 50, 100, 300 and 1000 msec).

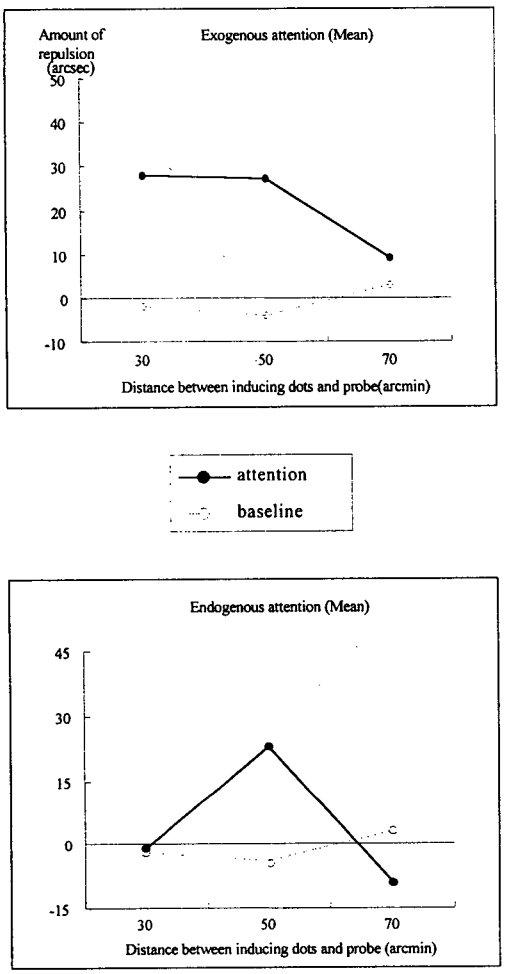
Furthermore, the control condition was included to find the baseline of effect in which the procedure was same as the one in exogenous condition only except the blinking of inducing dot. Thus, each observer was tested in six sessions, two for exogenous, two for endogenous and two for control conditions.

2.2 Results





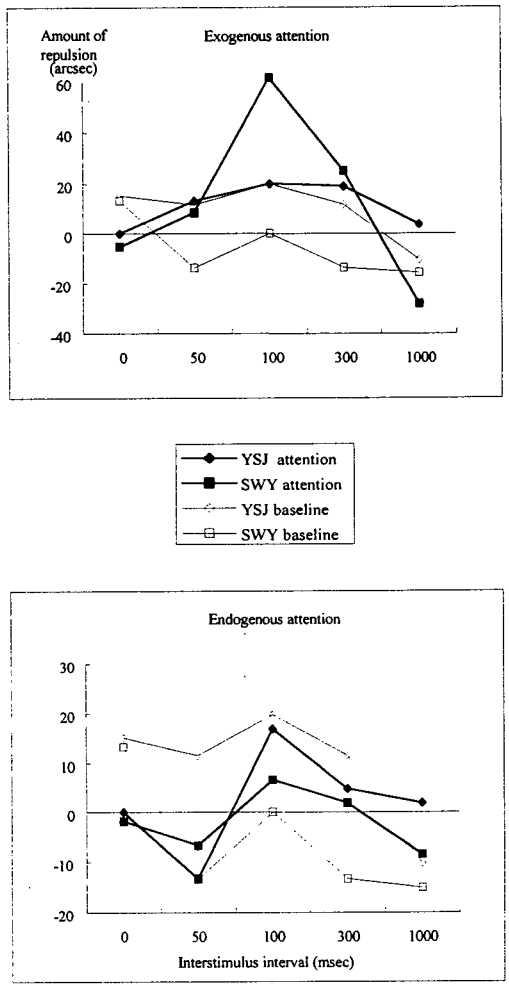


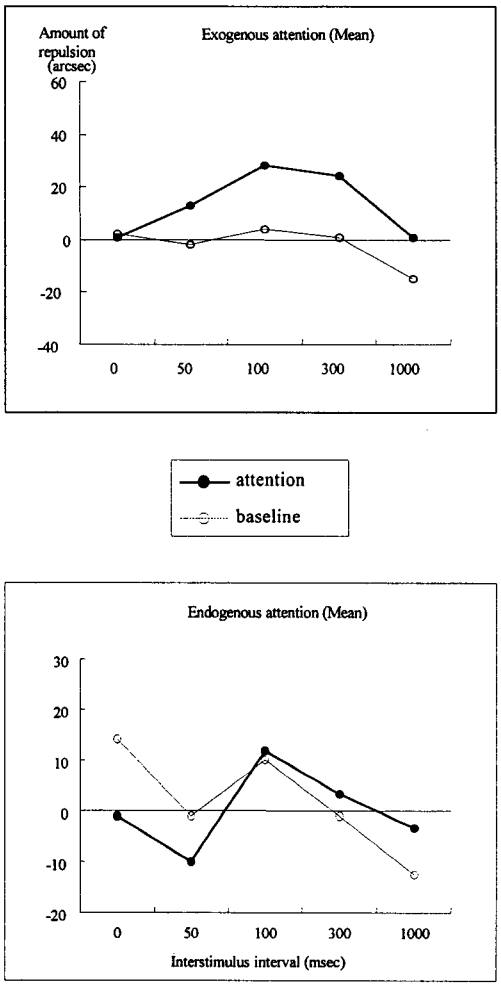


(Fig. 2) Attentional effects by distances from Experiment 1. Repulsion effects were plotted as functions of distances. In all charts, thick lines with solid marks represent experimental condition and thin lines represent control condition.

The results from experiment 1 are shown in Figure 2 and 3, separately plotted for exogenous and endogenous, distance and ISI conditions. Each left column of the chart shows the means of 18/30 blocks pooled for two individuals and right column for averaged sum of two observer's data.

Panels in Fig. 2 represent conditions with variable distance while the ones in Fig. 3 represent conditions with variable ISI. Attentional effect in terms of repulsion is expressed by the difference between the dotted line(control condition) and the solid one(experimental condition). In the all graphs of Figure 2, the solid lines are always above the control lines. That means, in distance condition whether it is exogenous or endogenous, there is a repulsion effect. This effect is strongest at the shortest distance in exogenous condition and declines with increase of distance. For the endogenous condition the repulsion effect is also found but is strongest at the middle(50') distance.





(Fig. 3) Attentional effects by ISI from Experiment 1. Repulsion effects were plotted as functions of interstimulus interval.

As shown in Fig. 3, similar result was found in the ISI condition. In an ISI range of 0-100msec repulsion (positive effect) is obtained, which tends to reverse at an ISI of 300msec and seems to disappear at the longest ISI of 1000msec. These results indicate that a repulsion of attended objects occurs and that this effect is stronger in exogenous than in endogenous condition.

2.3 Discussion

It was confirmed from Experiment 1 that a vertical line is perceived as repelled away from the focus of attention. Repulsion effect occurs for cue-induced and voluntarily-induced conditions, as well as for their corresponding distance- and ISI- subconditions. These results are consistent with the findings by Suzuki and Cavanagh(1997), who report the repulsion of objects from the locus of attention. Furthermore, repulsion seems to fade out with increasing attention-inducing distance and ISI, suggesting that effect of attention shows spatial and/or temporal gradient.

Since it is possible to attend to multiple loci(Yantis & Johnson, 1990), further questions arise whether repulsion effect can be obtained from another experimental designs, and whether the attentional effect differs when directed to more than one location of the visual field. In order to examine these questions, following experiment was carried out.

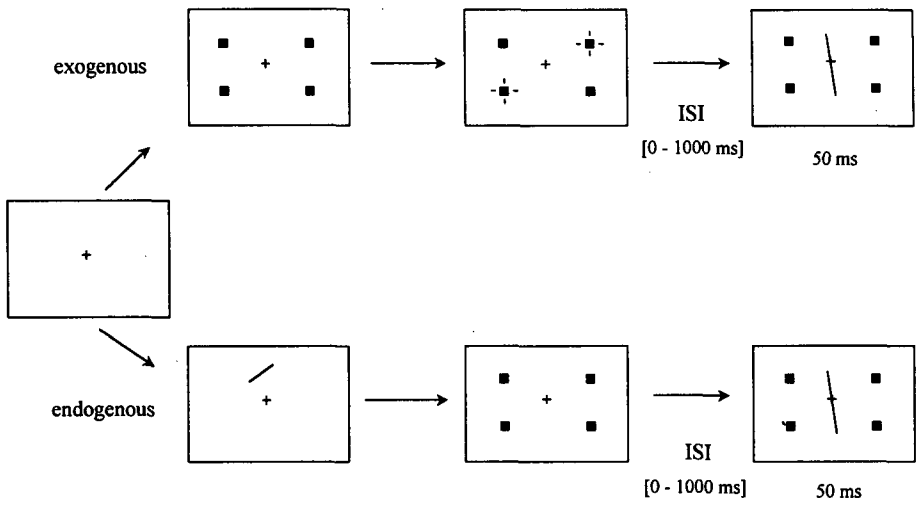
3. Experiment 2

This Experiment was designed to test repulsion effect and so closely related to the previous one. Two locations in visual field were attended in parallel and two-directional repulsion was tested. It was expected by cueing the lower left and upper right region close to a vertical line, that the line would be perceived as tilted in the opposite direction. Moreover the effect was expected to decline with increasing attention-inducing distance and ISI.

3.1 Method

Subjects. Three observers were participated in this Experiment. Two of them were the persons who took part in previous experiment. All observers had normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus was



(Fig. 4) stimulus configuration and the procedure of Experiment 2.

the same as in Experiment 1. The stimuli used in this experiment are shown in Fig. 4. Every stimulus was white on a gray background.

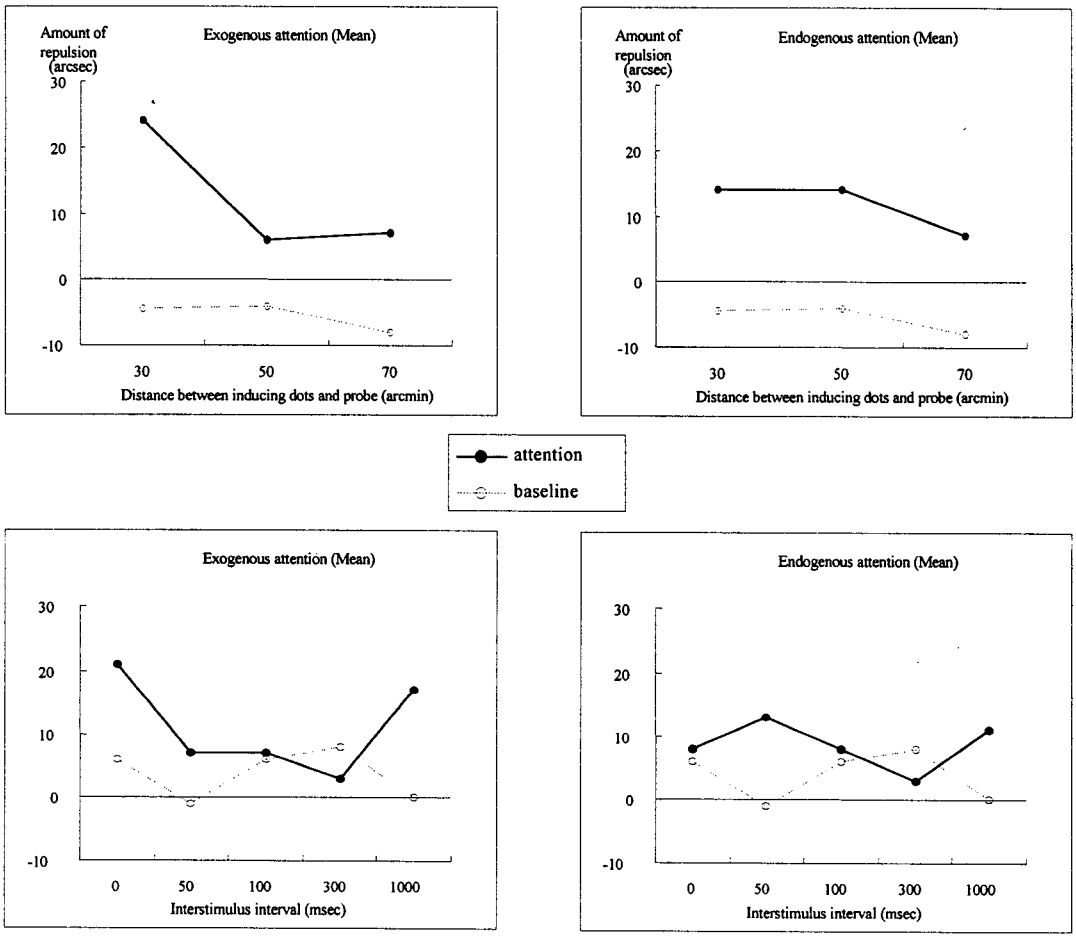
The vertical line in the center of the display was the probe stimulus (2° long and 1′ wide). The effect of repulsion was measured with the amount of line tilt against the veridical alignment. Four inducing dots which have 5′ of radius were used as the attentional cues. Attention-inducing distance was varied as 30′, 50′ and 70′. In exogenous condition two diagonally located dots, e.g. the lower left and upper right or vice versa, started blinking simultaneously in order to attract the observer's attention, while in endogenous conditions the subjects had to voluntarily direct attention to the diagonally aligned dots previously indicated by an example tilted line.

Procedure. The procedure of Experiment 2 was exactly same as the Experiment 1 except the configuration of stimulus. In the exogenous condition four small attention-inducing dots appeared for 400msec symmetrically to the upper and the lower part of the fixation cross, whereby two diagonally aligned dots(upper right and lower left or upper left and lower right) started blinking in order to attract attention. With an ISI(50msec in the distance subcondition or ranging from 0 - 1000msec in the ISI subcondition), a vertical line was flashed for 50msec followed by a blank screen. In the endogenous conditions a tilted line was presented above the fixation cross for 300msec to indicate to which of the following dots the observer should voluntarily shift attention. After pushing a button followed by an ISI, the probe line was again flashed for 50msec.

At the end of each trial the subject indicated in a 2AFC manner whether the probe was perceived as tilted clockwise or counterclockwise. Again, in an up-and-down staircase method with 6 reversals we determined the PSE between an imagined veridically aligned probe and the percept of the real probe. The number of blocks per session was the same as in Experiment 1. Thus, each observer was again tested in six sessions, two for exogenous, two for endogenous and two for control conditions.

3.2 Results

The results of Experiment 2 are illustrated in Fig. 5. Only averaged effects over three subjects were plotted, separately for exogenous and endogenous distance conditions. Each data point shows the mean of 18 blocks pooled for



(Fig. 5) The results from Experiment 2. The effects by distances are clear in graphs on upper row while the effects of ISI are not

three observers.

Both graphs show that in all distances the vertical line was perceived as tilted in the opposite direction. The strongest effects are seen for small distances (30′ in the exogenous, 30′ and 50′ in the endogenous condition). The results for conditions with variable ISIs do not show noticeable effects.

3.2 Discussion

In this Experiment we tested the attention effect on the percept of a vertical line when directing attention to the multiple regions in parallel. Although in some conditions this effect is not clearly seen, the overall results support the hypothesis that perceiving the vertical line as tilted is due to repulsion from both attended diagonal points. The effects of repulsion in Experiments 1 and 2 can be explained by the receptive-field-recruitment hypothesis suggested by Suzuki and Cavanagh(1997). However, since the repulsion is just one aspect of attentional distortions, it is necessary to investigate whether the receptive-field-recruitment hypothesis can hold as a successful explanation for effects in more complex stimulus configurations.

4. Experiment 3

Experiment 3 was conducted to test

attentional effects with respect to the percept of simultaneously presented horizontal lines. Whether paying attention simultaneously close to both ends of a horizontal line results in lengthening or in shortening of the line length. According to Suzuki and Cavanagh, the line should be perceived as shorter due to repulsion from both attentional loci. In terms of enlargement of space around the focus of attention, on the contrary, the line should be perceived as longer than its physical size because the space around the attentional loci is virtually extended by attention. Therefore, Experiment 3 was considered to be a differentiating experiment between the receptive-field-recruitment hypothesis and the space-enlargement hypothesis.

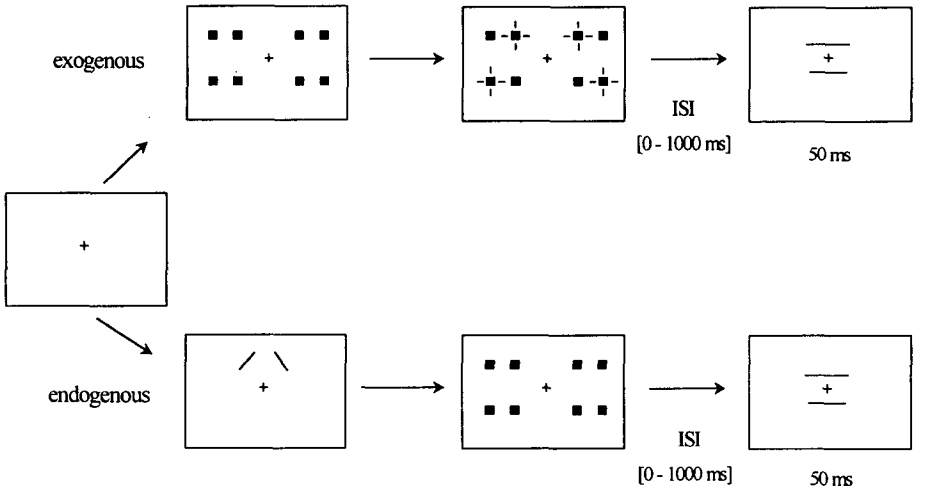
4.1 Method

Subjects. The same observers participated as in Experiments 2.

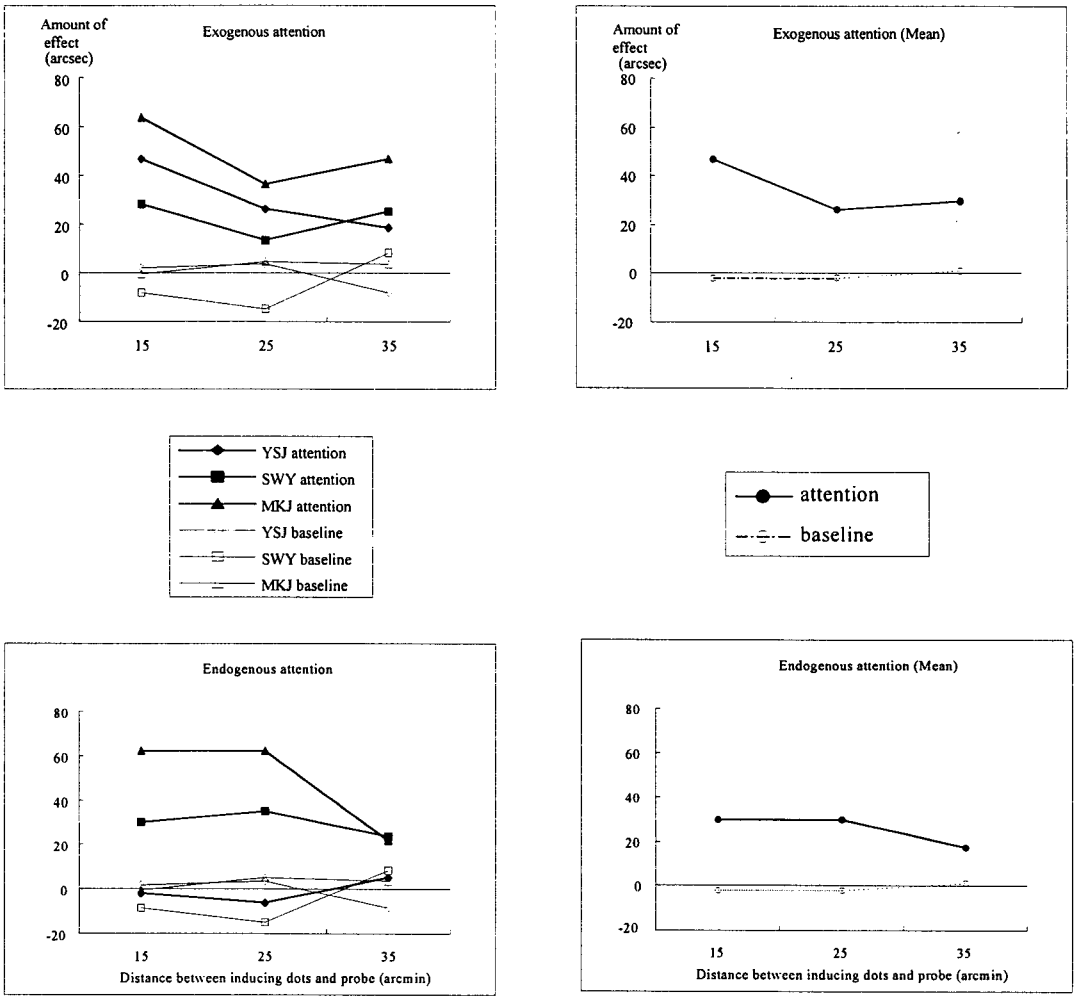
Apparatus and stimuli. The apparatus was the same as in the previous two Experiments. The stimuli used in Experiment 3 are shown in Fig. 6.

Two horizontal lines above and below the fixation cross were the probe stimuli. It had 1′ width and 50′ length in visual angle. Effects were measured as the amount of differing line length. The eight dots were used as the attentional cues, whereby in the exogenous condition four dots forming either an upright or an inverted trapeze, started blinking. In the endogenous condition the subject had to voluntarily attend to four specified dots, e.g. the upper inner dots and the lower outer ones, or vice versa. With an exception of attention-inducing distance(varied as 15′, 25′ and 35′), any other parameters such as ISI, probe duration etc were same as in the previous experiments.

Procedure. Each trial started with a fixation cross in the center of the screen. Fixation was maintained throughout the trial. Exogenous and endogenous conditions consisted of subconditions with variable attention inducing distances(15′, 25′, 35′) or variable ISI(0, 50, 100, 300, 1000msec). In the exogenous condition, eight inducing dots appeared arranged in two horizontal rows. Four of eight dots started blinking either converging upward or converging downward in order to attract the subject's attention. With an ISI two horizontal line segments were flashed for 50msec. The observer's task was to decide which one of the



(Fig. 6) The procedure and stimulus configuration of Experiment 3.



(Fig. 7) The results from Experiment 3. Both in individual and graphs, the attentional effects are clear. This effect decreases as increasing of distance.

lines was perceived as longer. Depending on the subject's response the lengths of the lines were varied in an up-and-down staircase procedure until they became subjectively equal.

In the endogenous condition, two lines previously presented above the fixation cross(converging upwards or downwards) indicated where to voluntarily shift attention. After having successfully shifted attention to the corresponding dots, the observer was to push a button and the horizontal lines were flashed. The task was to judge which line was perceived as longer until, in a staircase procedure, the lines became subjectively equal. All observers were tested in 6 sessions as in previous experiments.

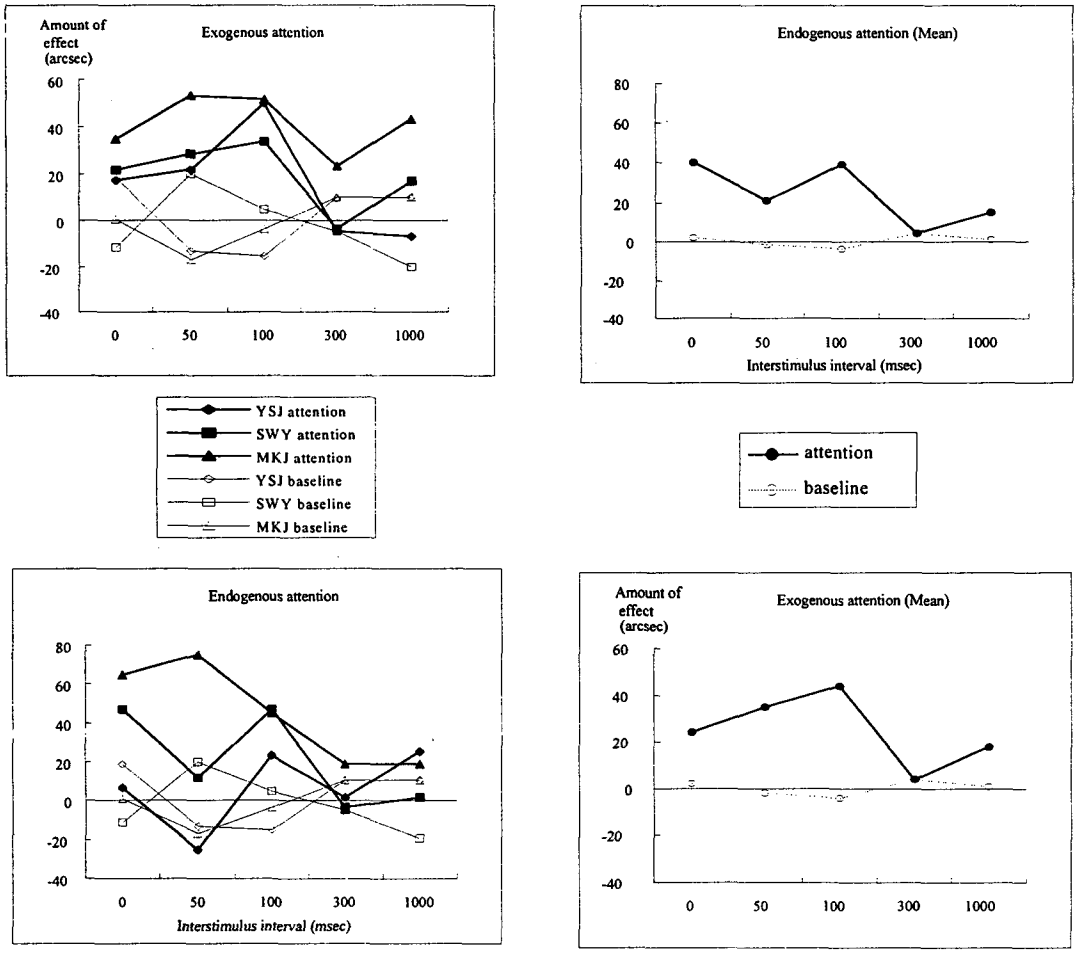
4.2 Results

The results of Experiment 3 for three individual observers are plotted in Figure 7 and 8, separately for exogenous and endogenous, distance and ISI conditions. Each data point shows the mean of 18 blocks pooled for three observers.

As clearly shown in Fig. 7 and Fig. 8, in all conditions the horizontal line closer to the attentional focus(close to the inner dots) was perceived as longer than the other horizontal line. For all conditions with variable distance and ISI the effect is consistent. The strongest effect was obtained in the shortest distance and ISI, decreased gradually, and disappeared at distance 35′ or ISI 300ms and more.

4.3 Discussion

Experiment 3 was supposed to be a crucial discrimination paradigm between the receptive-field-recruitment hypothesis and the space-enlargement hypothesis. In terms of shift of receptive field the horizontal line closer to the converging dots of the current experiment should have been perceived as shorter than the other one because the line was repelled away from the attentional foci, which were both ends of the line. In none of the conditions, however, the line closer to the attentional focus was perceived as shorter. This result can be explained only by the hypothesis postulating enlargement of space around the focus of attention. The enlargement of space might also



(Fig. 8) The results from Experiment 3. The effects of attention are also clear both in exogenous and endogenous ISI conditions.

provide an explanation for the traditional repulsion effects found in the previous experiments.

One might argue that the relationship to the real Ponzo illusion could be the reason for the results of Experiment 3. The well-known effect that a horizontal line located close to the converging ends of two vertical lines appears longer than an identical line close to the diverging ends, might reflect a strong influence in this experiment. In order to elaborate on this idea we conducted Experiment 4.

5. Experiment 4

As in Experiment 3, this experiment was carried out to test attentional effects on the percept of a horizontal line when attention was directed to both ends of that line. The difference from previous experiment was that attention was induced by just two simple blinking dots rather than by meaningful configuration such as Ponzo illusion. Unlike processes for getting results in the previous three experiments, only group data were collected since this experiment aimed to confirm the lengthening effect obtained from Experiment 3 with non-meaningful configuration of stimuli.

5.1 Method

Subjects. 15 undergraduate students participated in Experiment 4.

Apparatus and Stimuli. The apparatus was the same as in previous three experiments. The configuration of stimuli is shown in Fig. 9.

As in Experiment 3, two horizontal lines were the probes(50′ long and 1′ wide). Effects were measured as the amount of differing line length. Four dots were the attentional cues, whereby either the upper ones or the lower ones were blinking in order to attract the observer's attention. Only distance was varied as 30′, 50′ and 70′ with fixed ISI of 50msec.

Procedure. Each trial started with a fixation cross in the center of the screen. Fixation was maintained throughout the trial. Only exogenous and control conditions with their corresponding distance subconditions were included in this experiment. In the exogenous condition four dots appeared, forming the edges of a rectangle. Two of four dots(either upper pair or lower one) started blinking in order to attract the subject's attention. With an ISI fixed at 50msec two horizontal lines were flashed for 50msec. The task was to decide which line was perceived as longer until in an up-and-down staircase method they became subjectively equal.

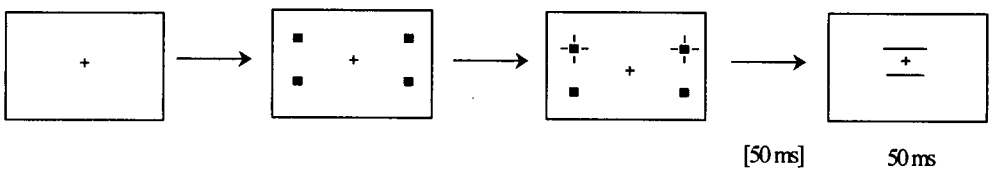
5.2 Results

The results of Experiment 4 for 15 observers are plotted in Fig. 10.

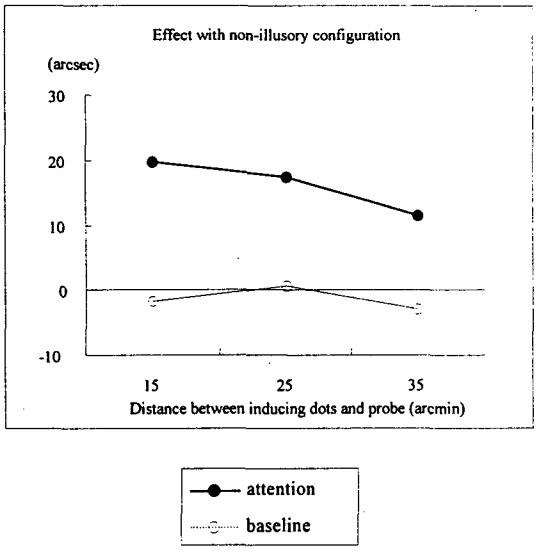
It is clearly indicated in Figure 10 that if attention is given to both ends of a line, then the line appears longer than a reference line which is farther from the attentional focus. This effect significantly declines with increasing attentional distance.

5.3 Discussion

Experiment 4 was conducted to test if the



(Fig. 9) The procedure and stimulus configuration of Experiment 4.



(Fig. 10) The results from Experiment 4. The effect of attention is obtained even when the attention was induced with simplified stimulus which had no meaningful configuration.

effect found in Ex

periment 3 depends on the configuration of stimuli. Since the results of Experiments 4 show the same tendency as Experiment 3 even in case that the configuration was too simplified for illusion effect to be involved, it was confirmed that presenting an object in a given attended area results in an enlarged percept of that object. Furthermore, the effect of enlargement decreases with increasing distance between attention-inducing cues and probe stimuli.

6. General Discussion

The current study shows that selective visual attention, cue-induced or voluntarily-induced, clearly affects the perception of briefly presented probes. In line with the previous study(Suzuki & Cavanagh, 1997), we found that a vertical line is perceived as repelled away from the focus of attention(Experiments 1 and 2). Moreover, the results indicate that the attention-induced repulsion effects show not only a spatial, but also a temporal gradient. Decreasing perceptual displacement with regard to increasing cue-probe distance is clear in all exogenous conditions. This result is consistent with previous findings that bottom-up attention has a sudden rise and a rapid decay(e.g. Nakayama & Mackeben, 1989). Since in comparison with Suzuki and Cavanagh's(1997) paradigm we used relatively small cue-vernier eccentricities, strong fall-off of the repulsion effect was found in cue-probe distance between 30′ and 70′, a range that Suzuki and Cavanagh did not take into account.

The phenomenon of repulsion can be explained by the receptive-field-recruitment hypothesis postulating a shift of receptive fields toward the focus of attention(Suzuki & Cavanagh, 1997; Connor, Gallant, & Van Essen, 1994) as well as by the hypothesis assuming an enlargement of perceived space around the attended area. Experiment 3 and 4 were conducted to distinguish between these hypotheses. The receptive-field-recruitment hypothesis would predict that attention close to both ends of a horizontal line results in a shortening percept of the line due to repulsion from both loci of attention. From Experiments 3 and 4, however, we found that the test line was clearly perceived as longer than the reference line of the same length when the attention was given to its vicinity. Thus the data from all experiments can only be explained by the space-enlargement hypothesis predicting an enlarged percept of objects presented in or close to the focus of attention.

The prediction of the current study challenges Tsal and Shalev's(1996) finding that attended lines are perceived as shorter than unattended ones. They argue that "inattention may reduce the clarity of the stimulus, increasing positional uncertainty of its boundaries, and consequently producing the perceived lengthening of the line." They suggest

an "attentional field hypothesis" in order to explain their finding, where the attentional fields, which might be components of a processing unit, for unattended objects are larger than those for attended ones. Stimuli falling in larger attentional field are mediated by a rounding-up mechanism resulting in extended percept. Compared to their memory-dependent categorical response, however, we used staircase method in which the observer should respond immediately with real percepts. The findings of the current study are consistent with those by Prinzmetal and Wilson (1997), who reported an overall tendency of underestimating the line length but the effect was less pronounced with attention. Further evidence for perceptual enlargement effects due to selective shifts of visual attention is also provided in a previous psychophysical investigation. Leiba and von Grünau(1995) presented two letters simultaneously and symmetrically on opposite sides of fixation. They reported an illusion of size, when one letter was preceded by a briefly flashed cue. The cued letter was perceived to be 5-15% larger than the comparison one.

Concerning the spatial distribution of selective visual attention, the data from current study can be best characterized by the simple gradient model of attention. In line with some investigations about the gradient distribution around the attentional focus(Henderson & Macquistan, 1993; Downing, 1988; Hughes & Zimba, 1985), in our study a peak of effect locates over the cued position and diminishes as distance from this location increase with gradient form.

From the Experiment 3 and 4, an additional result were also found. Presenting two horizontal lines simultaneously below and above the fixation cross resulted in a significant larger percept of the upper line even in the control condition. In two experiments which were not included in this study, similar asymmetry was obtained between two circles briefly presented to the left and to the right of the fixation cross. The circle presented in the left visual field was consistently perceived as larger than the one in right visual field. This asymmetry doesn't seem to have any relation with the subject's eye-dominance or handedness since this finding was replicated in successive studies with left handed subjects by Schelchshorn et al.(1998). They postulated that the asymmetry comes from basic bias in reading direction of the subject.

In conclusion, we found that selective visual attention(whether endogenous or exogenous) causes systematic perceptual distortions (stronger for exogenous than for endogenous condition) in a way that objects presented in or close to the focus of attention are perceived as enlarged. Furthermore these effects show a spatial and temporal gradient. In line with neurophysiological studies, we interpret the enlargement effect as the result of increased cortical involvement due to selective visual attention.

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