Mislocalization of a target toward subjective contours: Attentional modulation of location signals

Yamada, Yuki
Faculty of Human-Environment Studies, Kyushu University

Kawabe, Takahiro
Faculty of Human-Environment Studies, Kyushu University

Miura, Kayo
Faculty of Human-Environment Studies, Kyushu University

https://hdl.handle.net/2324/18927

出版情報：Psychological Research. 72 (3), pp.273-280, 2007-02-28. Springer-Verlag
バージョン：

ORIGINAL ARTICLE

Mislocalization of a target toward subjective contours: Attentional modulation of location signals

Yuki Yamada, Takahiro Kawabe, Kayo Miura

Abstract

This study examined whether a briefly presented target was mislocalized toward a subjective contour. Observers manually reproduced the position of a briefly presented peripheral target circle above a central fixation cross. A luminance contour, a subjective contour, or a no-contour stimulus was presented in either the left or right visual field, and a no-contour control was presented in the opposite visual field. After these stimuli vanished, a target circle was then presented. Consequently, the degree of mislocalization toward the subjective and luminance contours was the same; this indicated that image integration at a coarse spatial scale cannot explain mislocalization. Experiment 2 revealed that the mislocalization in Experiment 1 was not a result of eye movements. Experiment 3 found that the spatial attention allocated at the location of the luminance and subjective contours was more than that allocated at the no-contour stimulus. An attentional shift toward the task-irrelevant stimulus resulted in a mislocalization of the target.

This is a preprint version of the article published at Psychological Research 2008; 72: 273-280

Correspondence to:
Yuki Yamada, Faculty of Human-Environment Studies, Kyushu University,
6-19-1 Hakozaki Higashi-ku, Fukuoka 812-8581, Japan
yamadayuk@gmail.com

Introduction

The remembered location of a briefly-presented target is often mislocalized toward task-irrelevant stimuli (e.g., Nelson & Chaiklin, 1980; Schmidt, Werner, & Diedrichsen, 2003). This mislocalization was attributed to *landmark attraction effect* (Bryant & Subbiah, 1994) or *spatial memory averaging* (Hubbard, 1995; Hubbard & Ruppel, 1999). In this study, we refer to this kind of biased memory distortion toward task-irrelevant stimuli as *memory averaging*.

There are two explanations for the existence of memory averaging. First is the perceptual integration of the target and irrelevant objects at a coarse scale. As suggested by the Gestalt psychologists, proximal visual elements are perceived as a group (e.g., Wertheimer, 1923). Such perceptual grouping is partly attributed to image integration at a coarse spatial scale (Watt, 1988; Watt & Morgan, 1985). In this case, a low-pass filtering of proximal dots results in a large blob. It is believed that early vision decomposes the visual image into various scales, and thus, it is likely that proximal items can be integrated at early vision. We believe that the perceived position of each item in the blob is biased toward the center of the blob and that this may be the origin of memory averaging. Actually, the spatial distance between two perceptually grouped stimuli was perceived as closer than that between ungrouped stimuli (Coren & Girgus, 1980). Thus, the Gestalt law of "proximity" seems connect to spatial distortion and it may stem from coarse image integration.

The second possible explanation for memory averaging is an attention shift toward the task-irrelevant stimuli. In previous studies, an attentional shift along a bistable apparent motion path displaced the perceived position of a flash, which was on the midway of the path, in the direction of the attentional shift (Shim & Cavanagh, 2004, 2005). Furthermore, a briefly flashed target was reproduced with a greater bias toward the peripheral flashed landmark than the non-flashed landmark (Uddin, Kawabe, & Nakamizo, 2005a). They argued that a flashed landmark with an abrupt onset and offset resulted in an attentional shift toward it (Yantis & Jonides, 1984); moreover, this attentional shift caused a spatial distortion around the flash (see also Uddin, Kawabe, & Nakamizo, 2005b). Likewise, the final position of a moving object was reproduced with a bias toward the abrupt onset objects (Kerzel, 2002). Thus, the perceptual and memory mislocalizations of the target appear to occur in the direction of the attentional shift.

However, previous studies did not distinguish whether the mislocalization of a target toward task-irrelevant stimuli originated in image integration at a coarse scale or as a result of an attention shift. In this study, we examined memory averaging by using a subjective contour (e.g., Kanizsa, 1976). Using a subjective contour is advantageous in the following manner. First, it is not integrated with the target at a coarse scale (Figure 1). Second, using the subjective contour serves to test the relationship between memory averaging and visual attention. It is known that Kanizsa's subjective contour can be detected in parallel (Davis & Driver, 1994) and that such a popout item attracts attention (Joseph, Chun, & Nakayama, 1997; Wolfe, 1997). Moreover, the subjective contour captures visual attention (Ricciardelli, Bonfiglioli, Nicoletti, & Umiltà, 2001; Senkowski, Röttger, Grimm, Foxe, & Herrmann, 2005). Therefore, using a subjective contour enables us to directly investigate the role of visual attention in memory averaging and eliminates image integration at a coarse scale.

Experiment 1: Does mislocalization toward subjective contours occur?

Method

Observers Nine students from Kyushu University as well as the author (YY) voluntarily participated in this experiment. All participants had normal or corrected-to-normal visual acuity, and with the exception of YY, they were naive to the purpose of the study.

Apparatus and stimuli Stimuli were displayed on a CRT monitor (EIZO FlexScan T761, Japan) with a resolution of 1024 × 768 pixels; the vertical refresh rate was 75 Hz. Further, the viewing distance was 60 cm. A PC/AT compatible computer controlled the presentation of the stimuli and the collection of data. The luminance of the stimuli (a fixation cross, inducers, the luminance contour, a target circle, and the mouse cursor) was 33.0 cd/m2 and the luminance of the background was 99.7 cd/m2. The fixation cross was presented at the center of the screen. The target stimulus was a small circle with a radius of 0.17°. The inducer disks' visual angle of radius was 1°. Each of the four disks was centered at the corner of an imaginary rectangle with a height and width of 6° and 2°, respectively. As indicated in Figure 1, the following three types of stimuli were employed: (a) luminance contour, (b) subjective contour, and (c) without contour. Further, the luminance contour stimulus consisted of four inducers with an inside notch and a luminance contour with a width of 0.33°. The subjective contour stimulus consisted of four inducers with an inside notch that resulted in the perception of a subjective contour lacking luminance contours. The stimulus without any contours consisted of four inducers with an outside notch that did not yield any subjective contours. On a given trial, two of the three stimuli were simultaneously presented in the upper right and left visual fields, respectively. In the no-contour condition, the same stimulus without any contour was presented on each side. In other conditions, either the luminance contour or the subjective contour stimulus was presented in the left visual field and the no-contour stimulus was presented in the right visual field and vice versa. In other words, the luminance and subjective contours were never simultaneously presented on any given trial. The centers of the left and right stimuli were separated from one another by a visual angle of 10°. The central position of each stimulus was presented 3.33° above the fixation cross. The overall position of the stimulus was horizontally varied within 3.33°, although the distance between them was maintained. The target was presented on the middle position between the two stimuli. The following five trial types were conducted: (a) luminance contour stimuli presented on the left or right (LL or LR condition, respectively), (b)subjective contour stimuli presented on the left or right (SL or SR condition, respectively), and (c) no-contour stimuli presented on both the sides (no-contour condition).

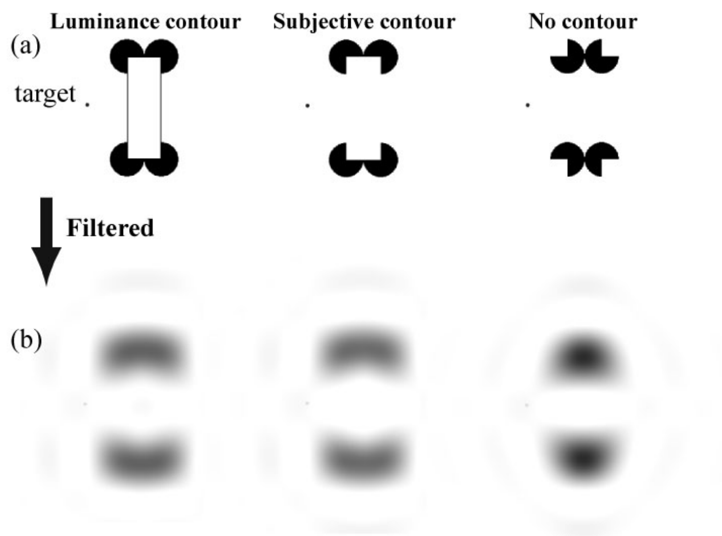

Figure 1: Examples of the stimuli used in this experiment.
(a) Left panel: A square with a luminance contour. Center: A square with a subjective contour. Right panel: The control stimulus. (b) Images output by the low-pass filter. In this scale, the small target image disappears.

Procedure and design The experiment was conducted in a dark room. Figure 2 presents a diagram of the temporal sequence on each trial. The observers were asked to maintain their gaze on the fixation cross and initiate each trial by pressing the spacebar. First, four filled disks without any notches were presented for 500 ms: This is a time required to shift attention to the disks. Immediately after, the disks were replaced by inducers with notches (and a luminance contour in LL and LR conditions) for a period of 300 ms. After a 200 ms inter-stimulus interval (ISI), the target was presented for 50 ms. Subsequently, after a 500 ms ISI, the mouse cursor—identical to the target circle—appeared at a random position on an imaginary circle with a radius of 3.3° that was centered at the same position as that of the target. The fixation cross was present throughout the trial. The observers were required to view the display and reproduce

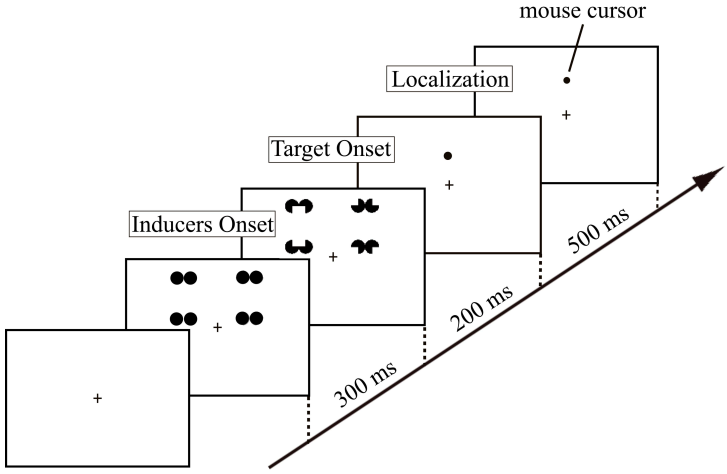

Figure 2: Schematic representation of the time course of a trial with a subjective contour in Experiment 1.

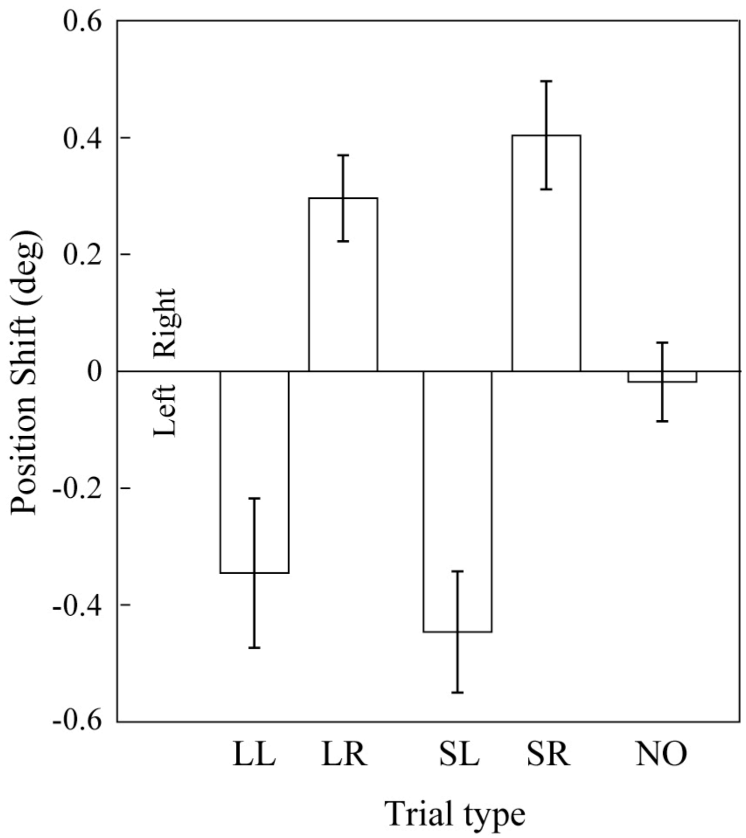

Figure 3: Observed localization bias.
The LL, LR, SL, SR, and NO represent the Luminance-Left, Luminance-Right, Subjective-Left, Subjective-Right, and No-contour conditions, respectively. The positive and negative values represent the rightward and leftward biases, respectively. Error bars denote standard errors.

the target position by clicking the left button of the computer mouse, while maintaining their gaze on the fixation cross; in other words, they were expected to move the mouse and position the cursor where they believed the circle had appeared. LL, LR, SL, and SR conditions were repeated 10 times, and the no-contour condition was repeated 20 times; thus, a total of 60 experimental trials were conducted in a pseudo-randomized order.

Results and Discussion

The bias and degree of mislocalization of the target position were calculated for each observer in each condition. The mean and standard errors are indicated in Figure 3. In further analysis, only the data of the x-coordinate was analyzed because the purpose of the experiment was to observe whether or not mislocalization occurred toward the peripheral contour (Sheth & Shimojo, 2004; Uddin et al., 2005a, b). A one-way analysis of variance (ANOVA) of the degree of biased mislocalization with trial type (LL, LR, SL, SR, and no-contour) as a factor revealed a significant main effect, $F(4, 36) = 17.58$, $MSE = 0.08$, $p < .001$.

Multiple comparisons using Ryan's method[1] (Ryan, 1960) indicated that the target positions in the LL and SL conditions were mislocalized significantly leftward than those in the no-contour conditions, $t(36) = 2.58$, $p < .02$, $t(36) = 3.37$, $p < .002$, respectively; further, the target positions in the LR and SR conditions were mislocalized significantly rightward than those in the no-contour conditions, $t(36) = 2.48$, $p < .02$, $t(36) = 3.33$, $p < .003$, respectively. However, neither mislocalizations in LL and SL conditions nor mislocalizations in LR and SR conditions differ from each other. In addition, we conducted a comparison against zero to observe whether the reproduced target position was different from the actual position. An analysis of 95% confidence intervals revealed significant mislocalization in the LL, LR, SL, and SR conditions (-0.35 deg ± 0.29 [average displacement ± 95% confidence intervals], 0.30 ± 0.17, -0.45 ± 0.23, 0.40 ± 0.21, respectively). However, the reproduced target position in the no-contour conditions did not differ from the actual one (-0.02 ± 0.15).

The results clearly indicated an obvious mislocalization of the target location toward the task-irrelevant Kanizsa's subjective contour as well as toward the luminance contour, regardless of the image features defining the contour. This supports the hypothesis that memory averaging is caused by attentional shifts resulting from the presence of the subjective contour; further, it

1. Ryan's test adopts nominal significant level given as follows: $p = 2*0.05 / (n*(m-1))$, where n means the number of group to be compared, and m means the distance defined as the number of group X_p satisfying $X_i \leq X_p \leq X_j$. Here, X_i and X_j are pair in a concerned hypothesis. On the other hand, the significant level in Bonferroni's test is set at $p = 0.05/{}_nC_2$, where n means the number of group to be compared.

eliminates the involvement of the outputs of coarse spatial filtering that did not result in a bias in each condition.

Further discussion is required as to whether or not the effect of the inducers with an inside notch was necessarily based on the presence of a subjective contour. Bryant and Subbiah (1994) found that the empty region of a figure could serve as a subjective landmark; consequently, it appears that the central region of the inducer-cluster could have perhaps functioned as a landmark even if a subjective contour itself was not perceived by the observers. In this regard, we would like to emphasize the effect of attention on the selection of empty regions. In the conditions with subjective contours (SL and SR conditions), two empty regions with or without a subjective contour always existed. Hence, if our results had stemmed merely from the effects of empty regions, the significant attraction of the targets toward the center of the inducers with subjective contours would not have been observed because both the empty regions would competitively attract the target's position. However, that was not the case. Therefore, we favor the interpretation that a subjective contour that drew attention attracted the target's position. To further strengthen our argument, in the next experiment, we first dismiss the possibility of mislocalization caused by eye movements (Experiment 2), and then, we verify that the subjective contours used in Experiment 1 engaged visual selective attention (Experiment 3).

Experiment 2: Is mislocalization caused by eye movements?

In this experiment, we address the role of eye movements in memory averaging. In the previous experiment, observers might have reflexively gazed at the subjective contours because these figures attention. Moreover, it should be noted that eye movements are commonly known as a causative factor of the mislocalization of a briefly presented target (e.g., Honda, 1989; Schlag & Schlag-Rey, 1995). Accordingly, we measured the observers' eye movements in conditions identical to those in Experiment 1.

Method

Observers Three people who were naive to the purpose of the study voluntarily participated in this experiment. All participants had normal or corrected-to-normal visual acuity.

Apparatus, stimuli, procedure, and design This experiment was identical to Experiment 1 in all aspects, with the exception that in Experiment 2, the observers' eye movements were monitored.

Results and Discussion

The data with a radial fixation error larger than 1.25° from the initial eye position was excluded from the analysis. As a result, on an average, 8.3% of the data were excluded as failed trials. Figure 4(a) is a representative example of successful eye movement trials and Figure 4(b) indicates the individual data. A one-way ANOVA revealed a significant main effect of trial type, $F(4, 8) = 14.17$, $MSE = 0.08$, $p < .002$. Multiple comparisons using Ryan's method indicated that the target positions in the LR condition was mislocalized significantly rightward than those in the no-contour conditions, $t(8) = 3.01$, $p < .02$.

Albeit slightly, the significant mislocalization was observed even in only three observers employed in this experiment. Regardless of the precise control of eye movements, a localization bias similar to that in the first experiment was observed in this experiment as well. Therefore, we believe that the oculomotor factor did not contribute to the results obtained in Experiment 1.

Experiment 3: Attentional allocation in the contours

This experiment aimed to confirm whether or not attention was directed to the inside of the

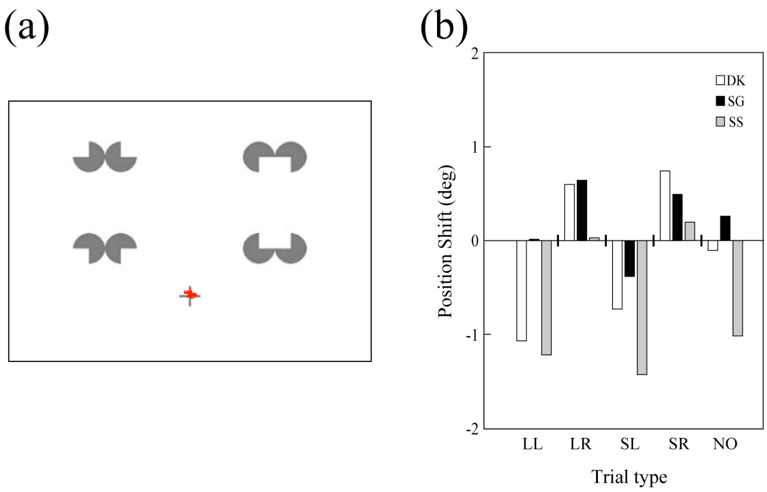

Figure 4

(a) Representative scan-path of eye movements drawn from an experimental trial by DK. Sixty eye positions, which were plotted as red circles, were sampled during a trial for 4 s at 15 Hz. All observers exhibited a similar tendency in the successful trials. (b) The observed localization bias from each observer (DK, SG, and SS). The LL, LR, SL, SR, and NO represent the Luminance-Left, Luminance-Right, Subjective-Left, Subjective-Right, and No-contour conditions, respectively. Values larger than 0 represent the rightward biases, and vice versa.

subjective contour used in Experiment 1. An illusory line motion (ILM) (Hikosaka, Miyauchi, & Shimojo, 1993) was employed as an index of the presence of attention (Kawahara, 2002). ILM is a kind of motion illusion in which a horizontal line appears to gradually unfold from a pre-cued location, while all parts of the horizontal line is presented simultaneously. In this experiment, a horizontal line between the two clusters of inducers was presented instead of the circular target used in Experiment 1. ILM is perceived from the subjective contours in the SL and SR conditions, when visual attention is selectively allocated at that location.

Method

Observers Eight students from Kyushu University voluntarily participated in this experiment. All participants had normal or corrected-to-normal visual acuity and were naive to the purpose of this study.

Apparatus, stimuli, procedure, and design This experiment was identical to Experiment 1 in all aspects, with the exception that in Experiment 3, the target circle was replaced with a horizontal white line with a height and width of 1° and 8.33°, respectively. The observers were required to report—by pushing an assigned key—whether the perceived motion direction of the line was leftward or rightward in a two alternative forced choice procedure. Further, the observers performed a total of 60 trials that included 10 repetitions of the four experimental contour conditions (LL, LR, SL, and SR) and 20 repetitions of the no-contour condition.

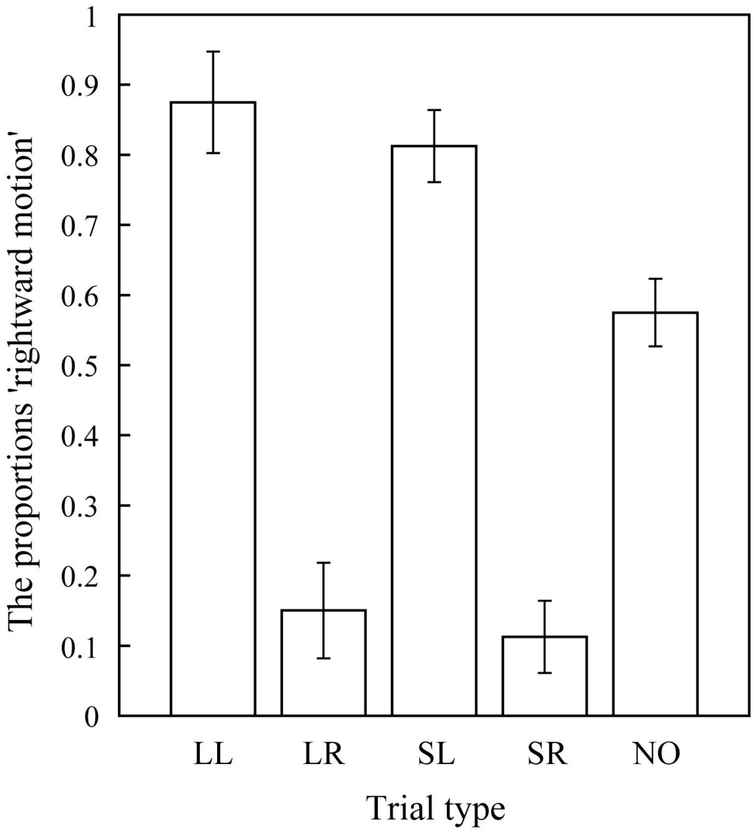

Figure 5: Proportion *rightward motion* denoting the observed localization bias in each condition in Experiment 1.

The LL, LR, SL, SR, and NO represent the Luminance-Left, Luminance-Right, Subjective-Left, Subjective-Right, and No-contour conditions, respectively. Values larger than 0.5 represent the rightward biases, and vice versa. Error bars denote standard errors.

Results and Discussion

The proportion *rightward motion* was calculated for each observer in each contour condition (Figure 5). Using these data, we conducted a one-way ANOVA with trial type as a factor; the results revealed a significant main effect, $F(4, 28) = 31.69$, $MSE = 0.03$, $p < .001$. Multiple comparisons using Ryan’s method indicated that the proportion *rightward motion* in the LL and SL conditions were significantly higher than those in the no-contour condition, $t(28) = 3.32$, $p < .003$, $t(28) = 2.63$, $p < .02$, respectively; further, those in the LR and SR conditions were significantly lower than those in the no-contour condition, $t(28) = 4.71$, $p < .001$, $t(28) = 5.12$, $p < .001$, respectively. However, neither the proportions *rightward motion* in LL and SL conditions nor the proportions *rightward motion* in LR and SR conditions differ from each other ($p > .05$). This indicates that the horizontal line appeared to unfold from the position of the luminance and subjective contours; subsequently, this suggests that the mislocalization observed in Experiment 1 may have stemmed from attentional allocation to the luminance and subjective contours.

General Discussion

This study aimed to clarify the contribution of an attentional shift to memory averaging between a target and the subjective contours by distinguishing it from a perceptual factor. In order to achieve this, we employed Kanizsa’s subjective contours that were presented prior to the target and demonstrated robust memory averaging (Experiment 1). Given that the target and inducers did not cause any blob at a coarse scale (Figure 1), it can be stated that this effect did not appear to stem from perceptual grouping. Furthermore, the involvement of eye movements was ruled out in mislocalization (Experiment 2). Additionally, Experiment 3 provided indirect evidence that the mislocalization in Experiment 1 can be attributed to an attention shift toward the luminance and subjective contours.

Our results concur with Tsal and Bareket's (2005) concept of attentional modulation of neural location signals. Several adjacent neural units (i.e., the cells in V1) are activated coincidentally at various intensities depending on the degree of spatial coincidence with the target. However, due to an overlap, the precise location of the target cannot be determined; this results in a coarse spatial distribution of the location signals. Thus, in nature, raw location signals are coarse. However, an attention shift toward the target location leads to a fine localization performance (Atkinson & Braddick, 1989). Therefore, it can be stated that attention spatially sharpens the location signals and shifts or skews the distribution of location signals toward the receptive field, which considerably overlaps the actual target position (Suzuki & Cavanagh, 1997). In Experiment 1, this function of attention might be the cause of the mislocalization.

Other phenomena pertaining to spatial distortion can be discussed in terms of attentional modulation of location signals. For example, a localization bias toward the fovea (foveal bias) (e.g., Müsseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999; Sheth & Shimojo, 2001; Uddin et al., 2005a, b) can also be explained by an attentional modulation of the distribution of location signals toward or around the fovea wherein visual attention dwells (Wolfe, O'Neil, & Bennet, 1998). Likewise, the fact that the ILM caused the endpoint of a horizontal line to be displaced in its direction (Yamada, Kawabe, & Miura, submitted) suggests the existence of an attentional modulation of location signals. In particular, an attention shift along the ILM (Hamm & Klein, 2002) appears to bias the location signal of a line edge toward its direction. It can be stated that the results obtained in Yamada et al. originate in a manner similar to the mechanism for attentional repulsion effect (Suzuki & Cavanagh, 1997) in which briefly presented vertically-aligned bars perceptually shift in the opposite direction of the pre-cued positions. Suzuki and Cavanagh proposed a model indicating that the attentional distortion of visual receptive fields leads to the repulsion effect. We propose that the attentional repulsion may result from the overshoot of an attentional shift from the cue to the bar; consequently, the bars appear to repulse the cue. A recent study using neural recording reported that visual receptive fields in MT in the primate visual cortex dynamically shifted in the direction of an attention shift (Womelsdorf, Anton-Erxleben, Pieper, & Treue, 2006); this finding is in accordance with the model suggested by Suzuki and Cavanagh.

In contrast, the results of our experiment revealed that the presentation of an irrelevant object near the target resulted in a mislocalization with an attraction toward—and not repulsion from—the irrelevant object. We suggest that this apparent contradiction in mislocalizations between the results of the previous studies and our results might stem from the dynamics of attention. In Suzuki and Cavanagh, it appeared that attention was more likely to shift from the cue to the probe because the cue and the probe were very similar in shape and size. On the other hand, in our study, the probe was dissimilar to the cue (irrelevant objects); moreover, the cue was more salient than the probe in shape and size. This might have been the cause for the delay in the disengagement of attention from the salient cue. Thus, in our study, the mislocalization of the target toward the cue occurred resulting in a contradictory bias of the mislocalization (i.e., attraction). Therefore, we speculate that the dwell time of attention at the cue location determines the attraction-repulsion. The apparent discrepancy of spatial distortions, attraction, and repulsion, appear to have a common mechanism underlain with attentional modulation of location signals.

References

Atkinson, J., & Braddick, O. J. (1989). 'Where' and 'what' in visual search. *Perception*, **18**, 181–189.

Bryant, D. J., & Subbiah, I. (1994). Subjective landmarks for perception and memory for spatial location. *Canadian Journal of Experimental Psychology*, **48**, 119–139.

Davis, G. & Driver, J. (1994). Parallel detection of Kanizsa subjective figures in the human visual system. *Nature*, **371**, 791-793.

Hamm, J. P., & Klein, R. M. (2002). Does attention follow the motion in the "shooting line" illusion? *Perception & Psychophysics*, **64**, 279–291.

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research*, **33**, 1219-1240.

Honda, H. (1989). Perceptual localization of visual stimuli flashed during saccades. *Perception & Psychophysics*, **45**, 162–174.

Hubbard, T. L. (1995). Environmental invariants in the representation of motion: Implied dynamics and representational momentum, gravity, friction, and centripetal force. *Psychonomic Bulletin & Review*, **2**, 322–338.

Hubbard, T. L., & Ruppel, S. E. (2000). Spatial memory averaging, the landmark attraction effect, and representational gravity. *Psychological Research*, **64**, 41–55.

Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a 'preattentive' feature search task. *Nature*, **387**, 805–807.

Kanizsa, G. (1976). Subjective contours. *Scientific American*, **234**, 48–52.

Kawahara, J. (2002). Facilitation of local information processing in the attentional blink as indexed by shooting line illusion. *Psychological Research*, **66**, 116-123.

Kerzel, D. (2002). Attention shift and memory averaging. *The Quarterly Journal of Experimental Psychology. Section A: Human Experimental Psychology*, **55**, 425–443.

Müsseler, J., Heijden, A. H. C. van der, Mahmud, S. H., Deubel, H., & Ertsey, S. (1999). Relative mislocalization of briefly presented stimuli in the retinal periphery. *Perception & Psychophysics*, **61**, 1646–1661.

Nelson, T. O., & Chaiklin, S. (1980). Immediate memory for spatial location. *Journal of Experimental Psychology: Human Learning and Memory*, **6**, 529–545.

Ricciardelli, P., Bonfiglioli, C., Nicoletti, R., & Umiltà, C. (2001). Focusing attention on overlapping and non overlapping figures with subjective contours. *Psychological Research*, **65**, 98–106.

Ryan, T. A. (1960). Significance tests for multiple comparison of proportions, variances, and other statistics. *Psychological Bulletin*, **57**, 318–328.

Schmidt, T., Werner, S., & Diedrichsen, J. (2003). Spatial distortions induced by multiple visual landmarks: How local distortions combine to produce complex distortion patterns. *Perception & Psychophysics*, **65**, 861–873.

Senkowski, D., Röttger, S., Grimm, S., Foxe, J. J., & Herrmann, C. S. (2005). Kanizsa subjective figures capture spatial attention: evidence from electrophysiological and behavioral data. *Neuropsychologia*, **43**, 872–886.

Sheth, B. R., & Shimojo, S. (2001). Compression of space in visual memory. *Vision Research*, **41**, 329–341.

Sheth, B. R., & Shimojo, S. (2004). Extrinsic cues suppress the encoding of intrinsic cues. *Journal of Cognitive Neuroscience*, **16**, 339–350.

Shim, W. M., & Cavanagh, P. (2004). The motion-induced position shift depends on the perceived direction of bistable quartet motion. *Vision Research*, **44**, 2393–2401.

Shim, W. M., & Cavanagh, P. (2005). Attentive tracking shifts the perceived location of a nearby flash. *Vision Research*, **45**, 3253–3261.

Schlag, J., & Schlag-Rey, M. (1995). Illusory localization of stimuli flashed in the dark before saccades. *Vision Research*, **35**, 2347–2357.

Suzuki, S., & Cavanagh, P. (1997). Focused attention distorts visual space: An attentional repulsion effect. *Journal of Experimental Psychology: Human Perception and Performance*, **23**, 443-463.

Tsal, Y., & Bareket, T. (2005). Localization judgements under various levels of attention. *Psychonomic Bulletin & Review*, **12**, 559–566.

Uddin, M. K., Kawabe, T., & Nakamizo, K. (2005a). Attention shift not memory averaging reduces foveal bias. *Vision Research*, **45**, 3301–3306.

Uddin, M. K., Kawabe, T., & Nakamizo, K. (2005b). Differential roles of distracters in reflexive and memory-based localization. *Spatial Vision*, **18**, 579–592.

Watt, R. J. (1988). *Visual processing: Computational, psychophysical and cognitive research*. London: Lawrence Erlbaum Associates.

Watt, R. J., & Morgan, M. J. (1985). A theory of the primitive spatial code in human vision. *Vision Research*, **25**, 1661–1674.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt. *Psychologishe Forschung*, **4**, 301–350.

Wolfe, J. M. (1997). In a blink of the mind's eye. *Nature*, **387**, 756–757.

Wolfe, J. M., O'Neil, P., & Bennet, S. C. (1998). Why are there eccentricity effects in visual search? Visual and attentional hypotheses. *Perception & Psychophysics*, **60**, 140–156.

Womelsdorf, T., Anton-Erxleben, K., Pieper, F., & Treue, S. (2006). Dynamic shifts of visual receptive fields in cortical area MT by spatial attention. *Nature Neuroscience*, **9**, 1156–1160.

Yamada, Y., Kawabe, T., & Miura, K. (submitted). Forward displacement at the end of illusory line motion. *Manuscript submitted for publication*.

Yantis, S. & Jonides J. (1984). Abrupt visual onsets and selective attention: evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, **10**, 601-621.