This is the peer reviewed version of the following article:
Mitsudo, H. (2003). Information regarding structure and lightness based on phenomenal transparency influences the efficiency of visual search. *Perception, 32(1),* 53-66,
which has been published in final form at http://dx.doi.org/10.1068/p3465.

Running head: TRANSPARENCY AND VISUAL SEARCH

Information regarding structure and lightness based on phenomenal transparency influences the efficiency of visual search

Hiroyuki Mitsudo
Kyushu University

Word count:
Abstract: 138
Main text: 5,362
Total: 6,950

Correspondence:
Hiroyuki Mitsudo
Department of Psychology Faculty of Letters
Kyushu University
6-19-1 Hakozaki Higashi-ku Fukuoka 812-8581 Japan
phone/fax: +81926422418
e-mail: hmitsudo@lit.kyushu-u.ac.jp

Abstract

Phenomenal transparency reflects a process which makes it possible to recover the structure and lightness of overlapping objects from a fragmented image. This process was investigated by the visual-search paradigm. In three experiments, observers searched for a target that consisted of gray patches among a variable number of distractors and the search efficiency was assessed. Experiments 1 and 2 showed that the search efficiency was greatly improved when the target was distinctive with regard to structure, based on transparency. Experiment 3 showed that the search efficiency was impaired when a target was not distinctive with regard to lightness (ie perceived reflectance), based on transparency. These results suggest that the shape and reflectance of overlapping objects when accompanied by transparency can be calculated in parallel across the visual field, and can be used as a guide for visual attention.

1 Introduction

Rapid visual selection within a visual field is critical for other human cognitive and motor functions (eg reading and grasping). Visual-search experiments (eg Treisman and Gelade 1980; Wolfe 1994) have provided insights into how the visual system uses two-dimensional retinal images rapidly to guide visual attention to a particular object. In the visual-search task, observers search for a target item among a variable number of distractor items, and reaction times (RTs) are measured. Search efficiency, defined as the slope of RTs x set-size function, is a useful index of how visual attention is guided by differences between the target and the distractor (Wolfe 1994; Duncan and Humphreys 1989). For example, when the target-distractor difference is large with regard to a "simple" feature (eg orientation or color), the slope is less than 10 ms/item: in such cases, search is called "efficient" (Wolfe 1994). Many studies have focused on image-based features and their combinations in which efficient search is produced (eg Treisman and Gormican 1988; Wolfe et al 1990). In a natural scene, however, visual information to identify a particular object is often fragmented in space and time for optical reasons such as occlusion and illumination.

The recovery of a three-dimensional scene from fragmented images is closely related to perceptual organization (eg Wertheimer 1938). Phenomenal transparency is one of the most intriguing examples of perceptual organization. When some stimulus conditions are satisfied, opaque fragments are organized into a perceptually transparent surface (Metelli 1974; Beck et al 1984; Kanizsa 1979; Kersten 1991). This phenomenon is thought to be involved in the recovery of the structure and lightness[1] of overlapping surfaces (Metelli et al 1985; Adelson 1993; Kingdom et al 1997). Structure based on transparency refers to the perceived shape of a transparent layer or the background. Metelli et al (1985) showed that the shape of a transparent layer depends on the luminance relations of regions, even when the outlines are the same. Lightness based on transparency refers to the perceived reflectance of a transparent layer or the background. Adelson (1993) and Kingdom et al (1997) showed that an illusory transparent layer affects the lightness of a patch behind it.

In some cases of perceptual organization such as shading, gestalt grouping, amodal completion and subjective contours (eg Enns and Rensink 1990; Gilchrist et al 1997; He and Nakayama 1992; Davis and Driver 1998), the relation between visual search and perceptual organization is clear: recovered (or organized) representation can be utilized for visual search. That is, even when a target is distinctive from distractors with regard to its recovered properties, but not image features, search also becomes efficient (Enns and Rensink 1990; Rensink and Enns 1998).

In contrast to the findings for other cases of perceptual organization, previous studies using transparent stimuli did not support the hypothesis--that organized (or recovered) representation can be utilized for visual search--for either the structure (Watanabe and Cavanagh 1992, 1993) or the lightness (Moore and Brown 2001). Watanabe and Cavanagh (1992, 1993) suggested that although early vision is involved in transparency, a transparent surface is not as effective as a luminance-defined surface with regard to the performance of psychophysical tasks (digit-identification and orientation-contingent color aftereffect). Moreover, Moore and Brown (2001) suggested that lightness based on transparency does not influence visual search. In their study, search performance was worse when a target was phenomenally distinctive with regard to lightness, than when a target was distinctive with regard to luminance. However, it is difficult to find a reason to regard transparency as an exception for the above hypothesis.

The present study examined whether information regarding structure and lightness based on transparency can be utilized for visual search, as in other cases of perceptual organization. Watanabe and Cavanagh (1992, 1993) did not demonstrate that the structure of a transparent surface is formed to guide visual attention. Thus, Experiments 1 and 2 in the present paper were designed to examine whether structure based on transparency can improve the efficiency of visual search. The stimuli used in Moore and Brown (2001) might prevent the visual system from using strong local cues for transparency (ie x-junctions). In their study, a large transparent filter covering half of all items was used, with the result that none of the items contained x-junctions. This configuration implies that lightness must be computed “between” search items in order to obtain efficient search. However, in the cases of shading, efficient search was found when lightness was calculated “within” each item (Enns and Rensink 1990; Sun and Perona 1996). Therefore, Experiment 3 re-examined whether lightness based on transparency can influence visual search, using a modified display whereby lightness was calculated within each item.

2 Experiment 1

Experiment 1 examined whether structure information based on transparency can influence the efficiency of visual search. In the present experiment, the participants’ task was to determine the presence or absence of a target defined by the spatial relations of the elements of search items. There were both control and transparent conditions, which differed only in terms of the relative location of the top and bottom elements of each item (Figure 1). It is known that this search is basically inefficient: RTs increase with an increase in set size, as long as no other information is available (Enns and Rensink 1990; Rensink and Enns 1995).

In the control condition, neither the target nor the distractor was transparent (Figure 1A). In the transparent condition, however, the target was a pattern triggering phenomenal transparency (Noguchi and Motoki 1972), the distractor was not; therefore, there was a target-distractor difference in structure based on transparency. That is, the target was perceived as two bars crossing, whereas the distractor was perceived as a cross rather than the two bars (Figure 1B). If the target-distractor difference can influence the search efficiency, then search in the transparent condition will be efficient.

In addition to the search task, to confirm that there was a target-distractor difference with regard to transparency in the transparent condition, a transparency-rating task was conducted.

2.1 *Methods*

2.1.1 *Participants*. Thirteen participants who were students of Chiba

University participated in the experiment. Six of the participants were assigned to the search task, while the other seven were assigned to the rating task. All had normal or corrected-to-normal acuity according to self-reporting, and all were naive to the purpose of the experiment.

2.1.2 *Apparatus*. The experiment was conducted on an Apple iMac DV with the use of PsyScope software (Cohen et al 1993). The participant's head was immobilized by a chin-rest, and the viewing distance was 60 cm.

2.1.3 *Stimuli*. The target and distractor were cross-shaped figures that were composed of two dark-gray squares (visual angle, 0.67° x 0.67°; luminance, 21 cd/m^2) and two light-gray squares (luminance, 35 cd/m^2). The luminance of the background and the center region of the items was 28 cd/m^2. The arrangement of the elements was slightly different in the control and transparent conditions. In both conditions, the targets were figures in which two light-gray squares were aligned horizontally, and two dark-gray squares were aligned vertically. The distractors were figures in which the lower square and the right-hand square of the target had changed places.

In the control condition, the squares of items were slightly displaced vertically (visual angle, 0.2°) so that none of the items were perceived as transparent (Figure 1A). This condition did not satisfy the figural condition (eg Metelli 1974) for transparency. In the transparent condition, the squares of each item were in contact with each other at their corners (Figure 1B). The target was perceived as two bars crossing, one of which was transparent. However, the distractor was perceived as a cross rather than the two bars crossing, because it contained x-junctions that do not trigger transparency (eg Anderson 1997).

Stimuli were presented in a rectangular field (visual angle, 11.9° x 15.8°). Search items could be presented at any of 12 locations in a 3 x 4 array, and they were randomly jittered by ±0.2° in order to minimize the influence of item collinearity. Note that the items were placed apart from each other to avoid forming a pseudo-target composed of two distractors. The target was present in half the trials, but was absent in the other half. In target-present trials, the target appeared at one of the 12 locations, and the remaining of items were all distractors. In target-absent trials, all the items were distractors. Search displays were formed of 1, 6 or 12 items chosen at random. Examples of target-present displays (set size, 12) are shown in Figure 2.

Insert Figures 1 and 2 about here

2.1.4 *Procedure*. In the search task, the participant's task was to determine the presence or absence of the target as quickly as possible, whilst maintaining accuracy. Participants were instructed to regard the item that had two light-gray squares aligned horizontally as the target. Participants responded by pressing the "1" or "3" keys on the keyboard with their right hand. In each trial, the search display was presented until the participant responded. The display was followed by accuracy feedback (a plus or minus sign) for 500 ms. The sign served as a fixation symbol for the next trial. In each condition, after 72 practice trials, each participant then underwent 216 trials, which were separated into three blocks. The order of the two conditions and the response keys were counterbalanced across participants.

In the rating task, the 12-items target-present search display with a white-bar cue that appeared at the upper left-hand side of one of the items was used. The participant's task was to rate the degree of transparency of the cued item, using a scale of 1 to 7 (1 = "no transparency, a mosaic-like pattern is seen", 7 = "a very high degree of transparency, two patterns are overlapping"). The cue indicated the target in half the trials, but indicated one of the distractors in the other half. In each trial, after the rated display was presented for 1,500ms, a response display was presented until the participants pressed one of the keys from "1" to "7", which were aligned horizontally on the keyboard. After eight practice trials, the participants then underwent 24 trials. The control and transparent conditions were presented in a randomized order.

2.2 *Results*

Rating task. The mean transparency ratings for each condition are shown in Figure 3. Two-way within-participant analysis of variance (ANOVA) was performed on the transparency ratings, with the factors of condition (control, transparent) and type of item (target, distractor). The main effects of condition and type of item were significant [$F(1, 6) = 86.97, p<.0001$; $F(1, 6) = 14.36, p<.01$, respectively], and the interaction was also significant, $F(1, 6) = 11.93, p<.02$. In the control condition, the transparency ratings of both items were extremely low, and the effect of type of item was not significant, $F(1, 6) = 0.02, p>.9$. In the transparent condition, the transparency rating of the target was very high, and the transparency rating was significantly higher for the target than for the distractor, $F(1, 6) = 25.12, p<.005$.

Insert Figure 3 about here

Search task. The mean correct RTs and error rates as a function of set size for each condition are shown in Figure 1. Slopes of linear regression of RTs against set size were calculated for each participant. In the control condition, the mean slopes were 26.7 and 54.1 ms/item for target-present and target-absent trials, respectively. In the transparent condition, the mean slopes were 7.0 and 23.1 ms/item for target-present and target-absent trials, respectively. One-way within-participant ANOVAs were performed on the slopes from the target-present and target-absent data, with the factor of search condition (control and transparent). The slopes were significantly lower in the transparent condition than in the control condition for both target-present and target-absent trials [$F(1, 5) = 18.75, p < .01$; $F(1, 5) = 17.06, p < .01$, respectively]. Mean error rates were 5.0% for the control condition and 3.9% for the transparent condition. Thus, there was no speed-accuracy trade-off between the two conditions.

2.3 *Discussion*

The results of the rating task confirmed that, only in the transparent condition, there was a target-distractor difference for structure based on transparency. The relatively low value of transparency rating for the distractor in the transparent condition is explained by the presence of the x-junctions that do not trigger transparency.

Search was much more efficient in the transparent condition than in the control condition, although in both conditions the targets were defined by the spatial relation of the elements. The slope of the control condition for target-present trials (26.7 ms/item) was consistent with that of inefficient search[2] (20-30 ms/item, eg Wolfe 1994). On the other hand, the slope of the transparent condition for target-present trials (7.0 ms/item) was consistent with that of efficient search (< 10 ms/item, eg Enns and Rensink 1991; Gilchrist et al 1997). The results indicate that search for a target defined by the spatial relations of the elements is improved by the increment of target-distractor difference for structure based on transparency. That is, in the transparent condition, the perceived structure of the target was two bars crossing, while that of the distractor was a cross or mosaic, rather than two bars. It is therefore likely that efficient search was observed in the transparent condition because the structure differences were calculated in parallel across the visual field, and because this information could be used to guide visual attention.

However, it is also possible that the results could be explained by the stimulus properties of search items, rather than by transparency. The first possibility is that the local difference in the configuration of the items between the control and transparent conditions could perhaps explain the difference in search performances seen in Experiment 1. That is, the small squares in the transparent condition were in contact with each other at their corners, and formed collinear edges, in contrast to those in the control condition. Because the collinear edge is considered as a cue to preattentive grouping (Gilchrist et al 1997), two light-gray squares in the distractor in the transparent condition might form oblique blobs. Therefore, search in the transparent condition is similar to search for a target defined by orientation, which is a typical case of efficient search. In contrast, search in the control condition might be inefficient because collinear grouping did not occur in this condition. Note that the grouping should be based on the collinear edge rather than low-spatial-frequency, because the low-spatial-frequency components of the two conditions seem to be nearly the same.

The second possibility is that the results could simply be explained by the “apparent” set size, the number of items presented in a display. That is, it is possible to consider that the number of “elements” presented in the control condition was four times as large as in the transparent condition, because the small squares of the items in the control condition were slightly separated from each other. Therefore, regardless of any target-distractor difference, if the observers regarded each item in the control condition as four separable items, then search performance would become about four times worse in the control condition than in the transparent condition. Incidentally, the slope in the control condition for target-present trials (26.7 ms/item) was about four times as large as that in the transparent condition (7.0 ms/item). To examine these two possibilities, I designed a visual-search task using stimuli that were slightly different from those of Experiment 1.

3 Experiment 2

Experiment 2 examined the two possibilities that might explain the results of Experiment 1: collinear-edge grouping (Condition A) and "apparent" set-size effect (Condition B). In Condition A, the target and distractor were identical to those in the transparent condition in Experiment 1, except for the removal of the upper dark-gray square of each item (Figure 4A). This manipulation disrupted phenomenal transparency in the target and distractor, although the local configuration of the light-gray squares remained the same as that in the transparent condition. If search is determined by collinear-edge grouping, search in Condition A as well as in the transparent condition will be efficient. However, neither the target nor the distractor in Condition A caused phenomenal transparency. Therefore, if search is determined by the structural difference based on transparency, then search in Condition A will be inefficient.

In Condition B, the target in the transparent condition and the distractor in the control condition of Experiment 1 were used (Figure 4B). In this condition, as well as in the control condition, each distractor was composed of the four squares that cause increment of "apparent" set-size. If search is simply determined by "apparent" set-size, search in Condition B will be inefficient. However, a target-distractor difference in the structure based on transparency existed because the target in the transparent condition was used. Therefore, if search is influenced by the structure based on transparency, then search in Condition B will be efficient.

3.1 *Methods*

3.1.1 *Participants*. Six students of Chiba University participated in the experiment. None of them had participated in Experiment 1. All had normal or corrected-to-normal acuity according to self-reporting, and all were naive to the purpose of the experiment.

3.1.2 *Apparatus*. The apparatus was the same as that used in Experiment 1.

3.1.3 *Stimuli*. The stimuli were similar to those in Experiment 1. In Condition A, the items were the same as that used in the transparent condition of Experiment 1, except for the removal of the upper dark-gray square of each item (Figure 4A). In Condition B, the target in the transparent condition and the distractor in the control condition of Experiment 1 were used (Figure 4B). The other properties of the stimuli were the same as those in Experiment 1.

3.1.4 *Procedure*. The procedure was identical to that of Experiment 1.

Insert Figure 4 about here

3.2 *Results*

The mean correct RTs and error rates as a function of set size for each condition are shown in Figure 4. In Condition A, the mean slopes were 24.8 and 51.6 ms/item for target-present and target-absent trials, respectively. In Condition B, the mean slopes were 1.2 and 8.1 ms/item for target-present and target-absent trials, respectively. The slope of Condition A was significantly higher than that in the transparent condition of Experiment 1 for the target-present trials, $F(1, 10) = 6.69, p < .05$. However, there was no significant difference in the target-absent trials, $F(1, 10) = 3.48, p < 0.1$. The slopes of Condition B were significantly lower than those in the control condition of Experiment 1 for both the target-present and target-absent trials, $F(1, 10) = 20.25, p < .005$; $F(1, 10)$

= 23.58, $p < .005$, respectively. Mean error rates were 3.5% for Condition A and 1.5% for Condition B. Thus, there was no speed-accuracy trade-off between the two conditions.

3.3 *Discussion*

In Condition A, although the local configuration of items was the same as that in the transparent condition, search was inefficient. This result suggests that efficient search observed in the transparent condition of Experiment 1 was not caused by collinear-edge grouping based on the local configuration. In Condition B, the number of elements presented in the display was the same as that in the control condition of Experiment 1. Nevertheless, search in Condition B was quite efficient[3], indicating that inefficient search in the control condition of Experiment 1 was not caused by increment of “apparent” set-size. Rather, search in the control condition was a typical case of search for a target defined only by the spatial relations of the elements (eg Enns and Rensink 1990). Therefore, it can be concluded that structure information based on transparency improves the search efficiency (other alternative accounts are discussed in General Discussion).

4 Experiment 3

In Experiment 3, to examine whether lightness based on transparency can be utilized for visual search, search efficiency in two conditions, control and transparent, was compared. Similar to Experiment 1, the two conditions were different in terms of the relative location of the top and bottom elements of each item. In both conditions, the participant’s task was to search for a target defined by luminance change within an item[4] (Figure 5). Luminance change can be considered as a distinctive feature: it is known that such search is basically efficient (Sun and Perona 1996). Therefore, if luminance information simply determines search performance, efficient search will be observed in both the control and transparent conditions.

In the transparent condition, however, the target-distractor difference was decreased with regard to lightness based on transparency (Figure 5B). That is, the target containing the luminance change was similar to the uniformly light distractor in lightness, because of an illusory transparent bar defined by outline (Kanizsa 1979). Therefore, if lightness information based on transparency can influence visual search, then search in the transparent condition will be inefficient.

4.1 *Methods*

4.1.1 *Participants*. Eight students of Kyushu University participated in the experiment. None of them had participated in the previous experiments. All had normal or corrected-to-normal acuity according to self-reporting, and all were naive to the purpose of this experiment.

4.1.2 *Apparatus*. The apparatus was the same as that used in Experiment 1. The viewing distance was 53 cm.

4.1.3 *Stimuli*. Stimuli were presented in a rectangular field (visual angle, 12.6° x 16.8°). Search items could be presented at any of 12 locations in a 3 x 4 array, and they were randomly jittered by ±1.2° in order to minimize the influence of item collinearity.

Each item was a cross-shaped figure that was composed of a horizontal bar (visual angle, 0.6° x 1.7°) and two outlined squares (visual angle, 0.6° x 0.6°; line thickness, 0.1°). The luminance of the light-gray regions of the target was 70 cd/m^2, while that of the medium-gray square was 55 cd/m^2. The luminance of the bar of the distractor was 70 cd/m^2. The luminance of the background and the inner regions of the outlined squares was 25 cd/m^2.

In the control condition (Figure 5A), outlined squares were separated from the horizontal bar (gap, 0.3°). In this condition, the medium-gray square of the target was interpreted as a lightness (ie perceived reflectance) change of the bar: the horizontal bar included a dark part. Neither the target nor the distractor was perceived as transparent, because the figural condition for transparency was not satisfied, as was also the case in Experiment 1.

In the transparent condition, outlined squares were in contact with the horizontal bar (Figure 5B). In this condition, the target was perceived as a figure in which a transparent bar was superimposed on top of the other bar. The distractor was perceived as a figure in which the horizontal bar occluded the vertical bar, and no transparency was perceived. Phenomenally, the horizontal bar of the target was a uniform light bar, as was the horizontal bar of the distractor, because the medium-gray square of the target tended to be perceived as having the same lightness as the rest of the horizontal light bar. After the experimental sessions, all participants were presented with the four types of items used in the experiment, and were asked about the percept of the stimuli on transparency. All participants reported that only the target item in the transparent condition had transparency.

The target was present in half the trials, but was absent in the other half. Search displays were formed of 1, 6 or 12 items chosen at random.

4.1.4 *Procedure*. The procedure, including the number of trials, practice and counterbalance on search conditions and response keys, was the same as that of the search task in Experiment 1, with the following exception. Participants were instructed to regard the item where the center region of the horizontal bar was dark against the rest of the bar as the target in both conditions.

Insert Figure 5 about here

4.2 *Results*

The mean correct RTs and error rates as a function of set size for each condition are shown in Figure 5. In the control condition, the mean slopes were 4.1 and 13.2 ms/item for target-present and target-absent trials, respectively. In the transparent condition, the mean slopes were 19.7 and 45.4 ms/item for both target-present and target-absent trials, respectively. The slopes were significantly higher in the transparent condition than in the control condition for target-present and target-absent trials [$F(1, 7)= 12.65, p <.01$; $F(1, 7)= 12.35, p <.01$, respectively]. Mean error rates were 2.1% for the control condition and 5.0% for the transparent condition. Therefore, there was no speed-accuracy trade-off between the two conditions.

4.3 *Discussion*

In the control condition, search was quite efficient (slope, 4.1 ms/item for target-present trials). This result confirms that luminance change within an object is a distinctive feature which can guide visual attention, when luminance change is interpreted as a reflectance change. However, search in the transparent condition was inefficient (slope, 19.7 ms/item for target-present trials), although the target was the same as that in the control condition, except for perceptual interpretation of the medium-gray square of the target. This result suggests that when the luminance change of the target is interpreted as being caused by a transparent bar, the target becomes similar to the distractors in terms of lightness. That is, the visual system discounts accidental luminance changes caused by transparent objects, even when we are searching for a target.

One might argue that these results can be explained simply by the physical difference of the items between the control and transparent conditions. However, I suggest that that explanation can be ruled out. For example, the outlined squares were separated from the horizontal bar in the control condition; they were in contact with the horizontal bar in the transparent condition. This difference could be regarded as a decrease in set size, which causes RT to decrease, as assumed in previous studies (eg Treisman and Gelade 1980). However, search was less efficient in the transparent condition than in the control condition. Therefore, the set-size effect cannot explain the results obtained in Experiment 3.

In addition, Experiment 3 also excludes another alternative account for Experiments 1 and 2. In Experiments 1 and 2, efficient search was obtained when the target was the "transparent" item: in the transparent condition of Experiment 1 and in Condition B of Experiment 2. The transparent item could be considered as a "familiar" figure: a transparent object might be more familiar than mosaic-like objects. Since it is known that an extremely familiar target such as one's own name is detected efficiently (Mack and Rock 1998), the efficient search obtained in Experiments 1 and 2 could simply have been due to the familiar-target effect. However, the results of Experiment 3 rule out this possibility, because inefficient search was observed even when a transparent target was used.

Moreover, the results obtained in Experiment 3 indicate another property of phenomenal transparency which cannot be used for visual search. That is, inefficient search was observed in the transparent condition, although the target-distractor difference existed in terms of transmittance (ie the target had transparency, but the distractors had no transparency). This suggests that efficient search cannot use transmittance information, indicating that the transmittance of objects is not calculated in parallel across the visual field.

5 General discussion

The three experiments clearly show that structure and lightness based on transparency can influence the efficiency of visual search. Accordingly, the data confirm that the hypothesis that recovered properties can be utilized for visual search, as noted in other cases of perceptual organization, is also true in the case of transparency. Moreover, Experiment 3 provides an answer to the problem of why the above hypothesis was not supported by Moore and Brown (2001), namely perceived reflectance can influence search performance when the lightness is calculated “within” each item, not between items as used in Moore and Brown (2001).

Can the results obtained in the present study be explained by previous models dealing with visual search[5]? I suggest that it would be impossible without assuming that some mechanism is involved in phenomenal transparency. For example, there is the preattentive object file hypothesis of Wolfe and Bennett (1997). In their model, a visual scene is parsed into objects containing some simple features. Efficient search is possible when the information being registered in each preattentive object file differs between the objects. This assumption implies that search performance depends on how a visual scene is parsed into objects.

How does the model of Wolfe and Bennett explain the data of the present experiments? In the transparent condition of Experiment 1, I used a target and distractor that were both composed of the same elements, and that shared the same outline. That is, the same information is registered in the preattentive object file of each cross-shaped item. Therefore, according to the prediction from Wolfe and Bennett’s model, search should be inefficient. However, efficient search was observed in the transparent condition of Experiment 1. To explain these results, I propose the additive assumption that a parsing process based on transparency occurs in the preattentive stage. According to this assumption the target is parsed into two bars, and the information registered in the preattentive object file is either “white and horizontal” or “black and vertical”. Because the information is different from those of the distractors, efficient search becomes possible. Note that the parsing process is not a simple mechanism such as the filtering of elements having the same contrast polarity. If such a mechanism determines search performance, search would always be efficient, whether or not transparency occurs. However, search in Condition A of Experiment 2 was inefficient due to the absence of any structure difference between the items, although the light-gray elements were identical to those in the transparent condition of Experiment 1. Therefore, in order to explain the results, the assumption of a parsing process based on transparency is necessary.

One might think that perceptual grouping without transparency can explain the results. Grouping within each item is also known to be a factor that affects search performance (Rensink and Enns 1995; Gilchrist et al 1997). For example, Gilchrist et al (1997) proposed two separate mechanisms, which group elements of each item by using luminance and edges. However, I suggest that neither grouping by luminance nor by edge is sufficient to explain the results. First, consider grouping effects by luminance. This grouping can be achieved by a low-spatial-frequency filtering, because it is thought to be insensitive to continuity in edge of elements of each item (Gilchrist et al 1997). Therefore, grouping by luminance predicts similar performances in the control and transparent conditions in Experiment 1. However, as shown in Figure 1, the results clearly ruled out this possibility. Second, grouping by edge is thought to be insensitive to contrast polarity of elements. In the transparent condition of Experiment 1, edges were identical between the target and distractor. Therefore, grouping by edge predicts inefficient search in the transparent condition. Clearly, the results also ruled out the possibility. Thus, simple grouping mechanisms not involved in transparency seem to be inadequate for explaining the results of the present study.

Can x-junctions, which are known to be a strong local cue for phenomenal transparency, explain the results? I think that a mechanism for detecting x-junctions in parallel cannot simply explain the results. That is, although both the target of the transparent condition in Experiment 1 and that of Condition A in Experiment 2 contained only these x-junctions that trigger phenomenal transparency, the search performances of the two conditions were quite different from each other, depending on whether or not the arrangement of the x-junctions produced phenomenal transparency. In other words, the results show that preattentive vision is sensitive to the arrangement of x-junctions.

Binocular disparity is also known as a cue which triggers and enhances the impression of transparency (Nakayama et al 1990; Anderson 1997). However, the impression did not greatly influence the performance of the tasks (Kingdom et al 1997; Moore and Brown 2001). In contrast, although only monocular cues were used in the present experiments, search performance varied greatly according to information based on transparency. The results can be interpreted as an extension of earlier findings regarding phenomenal transparency (Metelli 1974; Kanizsa 1979; Marr 1982; Beck and Ivry 1988), which stressed the necessity of monocular cues for triggering phenomenal transparency.

References

Adelson E H, 1993 “Perceptual organization and judgement of brightness” *Science* **262** 2042-2044

Anderson B L, 1997 “A theory of illusory lightness and transparency in monocular and binocular images: The role of contour junctions” *Perception* **26** 419-453

Beck J, Ivry R, 1988 “On the role of figural organization in perceptual transparency” *Perception & Psychophysics* **44** 585-594

Beck J, Prazdny K, Ivry R, 1984 “The perception of transparency with achromatic colors” *Perception & Psychophysics* **35** 407-422

Cheal M L, Lyon D, 1989 “Attention effects on form discrimination at different eccentricities” *The Quarterly Journal of Experimental Psychology* **41A** 719-746

Cheal M L, Lyon D R, 1992 “Attention in visual search: multiple search classes” *Perception & Psychophysics* **52** 113-138

Cohen J, MacWhinney B, Flatt M, Provost J, 1993 “PsyScope: an interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers” *Behavior Research Methods, Instruments, and Computers* **25** 257-271

Davis G, Driver J, 1998 “Kanizsa subjective figures can act as occluding surfaces at parallel stages of visual search” *Journal of Experimental Psychology: Human Perception and Performance* **24** 169-184

Duncan J, Humphreys G W, 1989 “Visual search and stimulus similarity” *Psychological review* **96** 433-458

Enns J T, Rensink R A, 1990 “Influence of scene-based properties on visual search” *Science* **247** 721-723

Enns J. T, Rensink, R A, 1991 “Preattentive recovery of three-dimensional orientation from line drawings” *Psychological Review* **98** 335-351

Gilchrist A, Kossyfidis C, Bonato F, Agostini T, Cataliotti J, Li X, Spehar B, Annan V, Economou E, 1999 “An anchoring theory of lightness perception” *Psychological Review* **106** 795-834

Gilchrist I D, Humphreys G W, Riddoch M, Neumann H, 1997 “Luminance and edge information in grouping: a study using visual search” *Journal of Experimental Psychology: Human Perception and Performance* **23** 464-480

He Z J, Nakayama K, 1992 “Surfaces versus features in visual search” *Nature* **359** 231-233

Kanizsa G, 1979 *Organization in vision* (New York: Praeger)

Kersten D, 1991 “Transparency and the cooperative computation of scene attributes”, in *Computational Models of Visual Processing* Eds. M S Landy, J A Movshon (Cambridge, MA: MIT Press) pp 209-228

Kingdom F A A, Blakeslee B, McCourt M E, 1997 “Brightness with and without perceived transparency: when does it make a difference?” *Perception* **26** 493-506

Mack A, Rock I, 1998 *Inattentional blindness* (Cambridge, MA: MIT Press)

Marr D, 1982 *Vision* (New York: W. H. Freeman and Company)

Metelli F, 1974 “The perception of transparency” *Scientific*

American **230** 90-98

Metelli F, Da Pos O, Cavedon A, 1985 “Balanced and unbalanced, complete and partial transparency” *Perception & Psychophysics* **38** 354-366

Moore C M, Brown L E, 2001 “Preconstancy information can influence visual search: the case of lightness constancy” *Journal of Experimental Psychology: Human Perception and Performance* **27** 178-194

Nakayama K, Shimojo S, Ramachandran V S, 1990 “Transparency: relation to depth, subjective contours, luminance, and neon color spreading” *Perception* **19** 497-513

Noguchi K, Motoki M, 1972 “Illuminance as a determinant of apparent transparency” *Japanese Psychological Research* **14** 204-208

Rensink R A, Enns J T, 1995 “Preemption effects in visual search: Evidence for low-level grouping” *Psychological Review* **102** 101-130

Rensink R A, Enns J T, 1998 “Early completion of occluded objects” *Vision Research* **38** 2489-2505

Sun J, Perona P, 1996 “Early computation of shape and reflectance in the visual system” *Nature* **379** 165-168

Treisman A, Gelade G, 1980 “A feature integration theory of attention” *Cognitive Psychology* **12** 97-136

Treisman A, Gormican S, 1988 “Feature analysis in early vision: evidence from search asymmetries” *Psychological Review* **95** 15-48

Watanabe T, Cavanagh P, 1992 “The role of transparency in perceptual grouping and pattern recognition. *Perception* **21** 133-139

Watanabe T, Cavanagh P, 1993 “Surface decomposition accompanying the perception of transparency” *Spatial Vision* **7** 95-111

Wertheimer M, 1938 “Laws of organization in perceptual forms”, in *A source book of Gestalt psychology* Ed. W D Ellis (London: Kegan Paul) pp71-88

Wolfe J M, 1994 “Guided search 2.0: a revised model of visual search” *Psychonomic Bulletin & Review* **1** 202-238

Wolfe J M, Bennett S C, 1997 “Preattentive object files: shapeless bundles of basic features” *Vision Research* **37** 25-43

Wolfe J M, Yu K P, Stewart M I, Shorter A D, Friedman-Hill S R, Cave K R, 1990 “Limitations on the parallel guidance of visual search: Color x color and orientation x orientation conjunctions” *Journal of Experimental Psychology: Human Perception and Performance* **16** 879-892

Author's Note

Hiroyuki Mitsudo, Graduate School of Human-Environment Studies, Kyushu University.

A portion of this study was presented at the First Asian Conference on Vision in Hayama, Japan, July 2001.

I thank Sachio Nakamizo, Yoshie Kiritani, Makoto Ozeki and Haruo Hibino for their helpful comments on my study.

I also thank Miss K. Miller (Royal English Language Centre, Fukuoka, Japan) for her revision on the English used in this paper.

I am also grateful to S. P. McKee and the three anonymous reviewers for their positive and constructive comments.

Correspondence should be addressed to Hiroyuki Mitsudo at the Department of Psychology, Faculty of Letters, Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan. Electronic mail may be sent to mitsudo@psycho.hes.kyushu-u.ac.jp.

Footnotes

[1] In the present paper, I do not distinguish the term “lightness” (ie perceived reflectance) from “brightness” (ie perceived luminance), although some researchers (Adelson 1993; Kingdom et al 1997) acknowledge a strict distinction between the two terms. According to the anchoring theory of lightness perception (Gilchrist et al 1999), the difference comes down to whether the context is global (ie brightness) or local (ie lightness), and the concept of lightness is more comprehensive. Therefore, in the present paper, I have adopted the term “lightness”.

[2] In the present paper, I focused on slopes for target-present trials to assess search performance because they are thought to be more robust and reliable than those of target-absent trials (eg Wolfe and Bennett 1997). Although some research indicates that search does not fall into two distinct categories (parallel and serial, eg Cheal and Lyon 1992), this does not reduce the importance of factors influencing search difficulty, measured by search slopes.

[3] Search seems to be more efficient in Condition B of Experiment 2 than in the transparent condition of Experiment 1. This might be due to the spacing difference between the target and distractor in Condition B.

[4] It is possible to say that the target was defined by luminance itself, because the medium-gray square appeared only on the target. In either case, search should be efficient, if transparency has no effect on search performance.

[5] Target eccentricity from fixation is also known to be a factor that influences search performance (eg Cheal and Lyon 1989). It is possible that an inefficient search is produced by an increase of RTs only in large target eccentricity. To determine whether search efficiency is explained by target eccentricity, I reanalyzed RTs between large (the leftmost and rightmost columns in the display) and small (the two center columns) eccentricities for all experiments, and categorized RTs according to search performance (efficient: transparent in Experiment 1, Condition B in Experiment 2 and control in Experiment 3; inefficient: the other conditions). Two-way within-participant ANOVA was performed on the RTs, with the factors of eccentricity (small, large) and type of search (efficient, inefficient). RTs significantly increased with eccentricity, $F(1, 19) = 39.84, p<.0001$. However, more importantly, RTs were shorter in efficient search than in inefficient search, for each eccentricity [small, $F(1, 19) = 207.08, p<.0001$; large, $F(1, 19) = 379.84, p<.0001$]. The mean differences between the two search conditions were 147 ms in the small eccentricity and 199 ms in the large eccentricity. Therefore, performance differences between search conditions in this study are not explained by target eccentricity.

Figure Captions

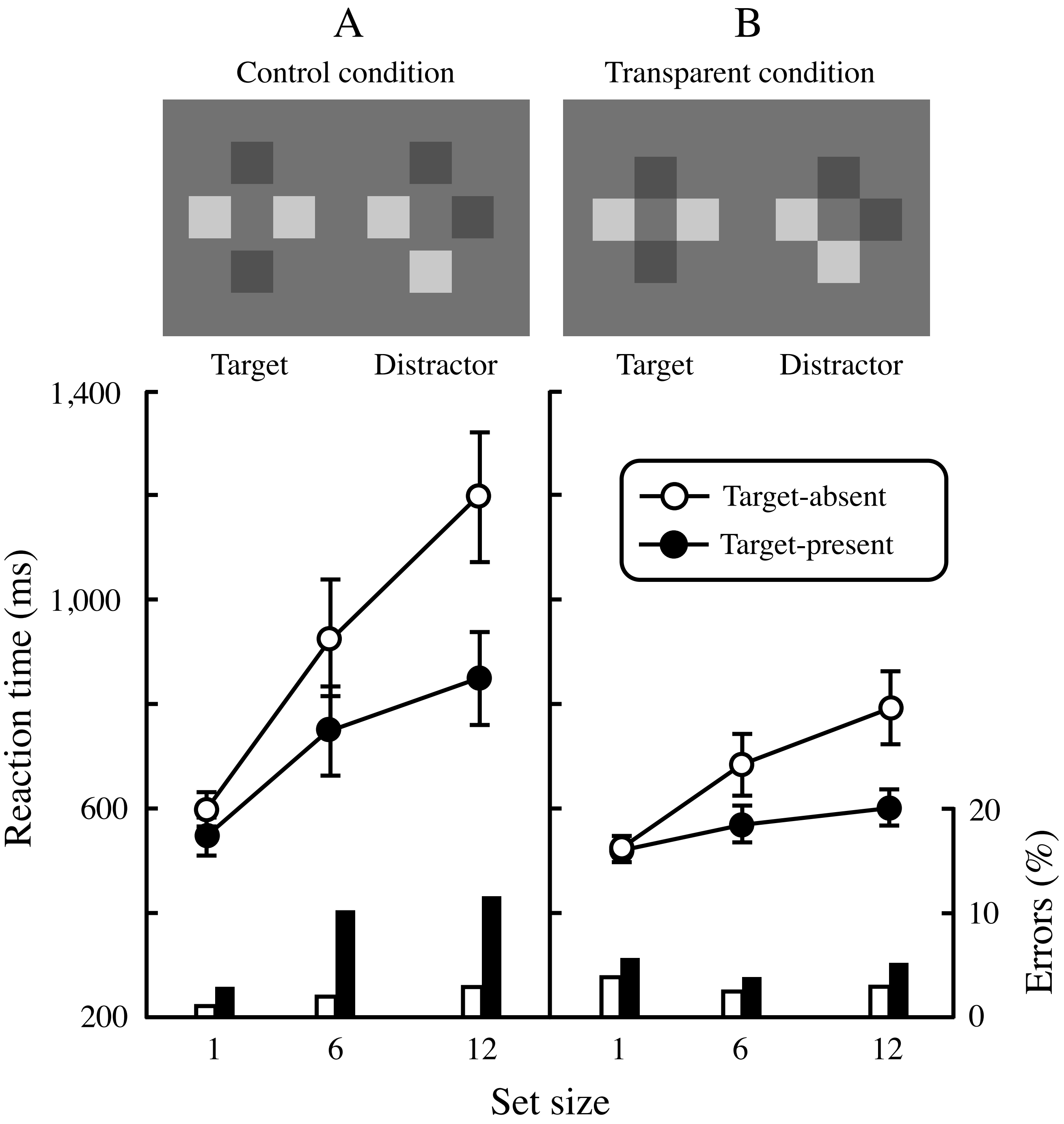
Figure 1. The stimuli, mean reaction times and mean error rates as a function of set size in Experiment 1. A: the target and distractor in the control condition. B: those in the transparent condition. Filled circles represent data from target-present trials; open circles represent data from target-absent trials; vertical bars attached to RT data represent standard errors.

Figure 2. Examples of target-present displays (set size 12). A: the control condition. B: the transparent condition.

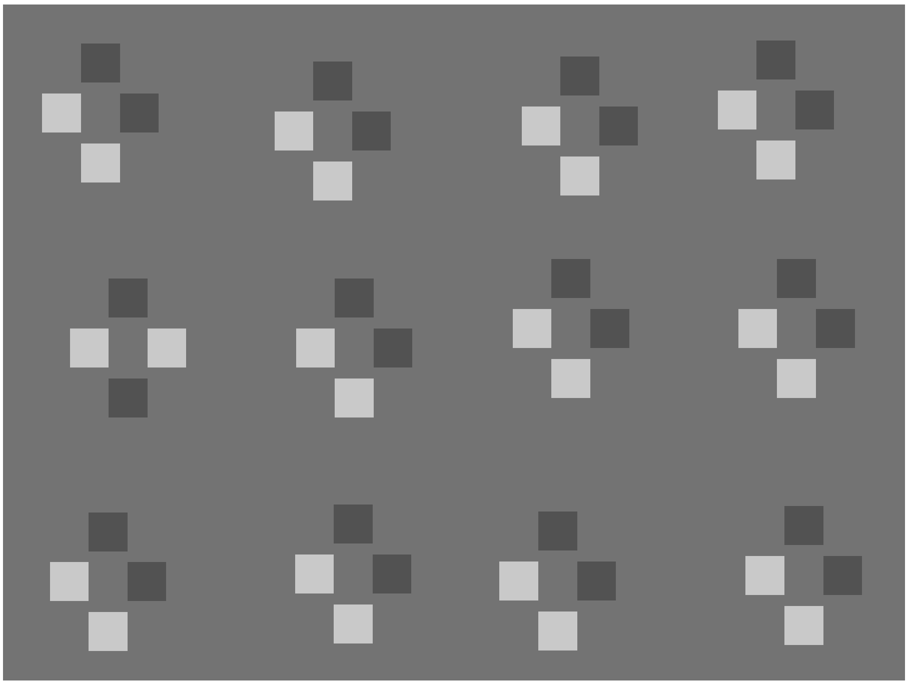
Figure 3. The mean transparency ratings in Experiment 1. Vertical narrow bars represent standard errors.

Figure 4. The stimuli, mean reaction times and mean error rates as a function of set size in Experiment 2. A: Condition A. B: Condition B. Filled circles represent data from target-present trials; open circles represent data from target-absent trials; vertical bars attached to RT data represent standard errors.

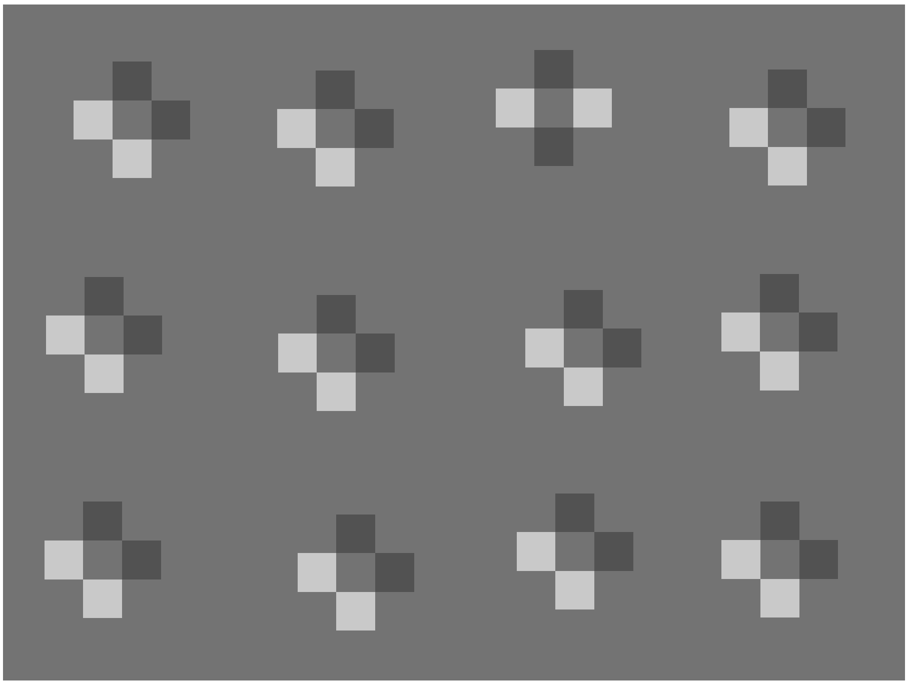
Figure 5. The stimuli, mean reaction times and mean error rates as a function of set size in Experiment 3. A: the control condition. B: the transparent condition. Filled circles represent data from target-present trials; open circles target-absent trials; vertical bars attached to RT data represent standard errors.

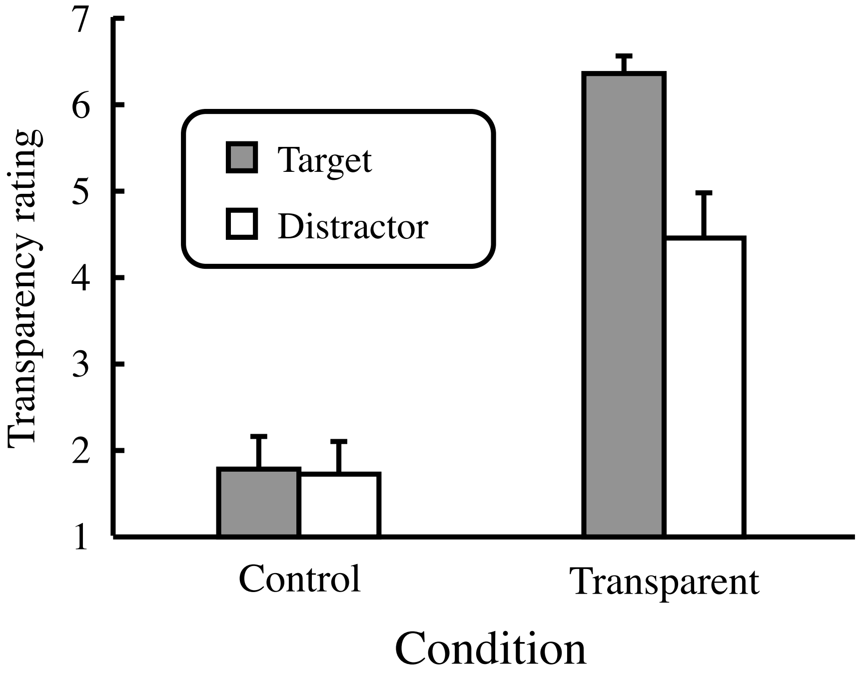

A
Control condition
Target
Distractor
B
Transparent condition
Target
Distractor
1,400
1,000
600
200
Reaction time (ms)
Target-absent
Target-present
20
10
0
Errors (%)
1
6
12
1
6
12
Set size

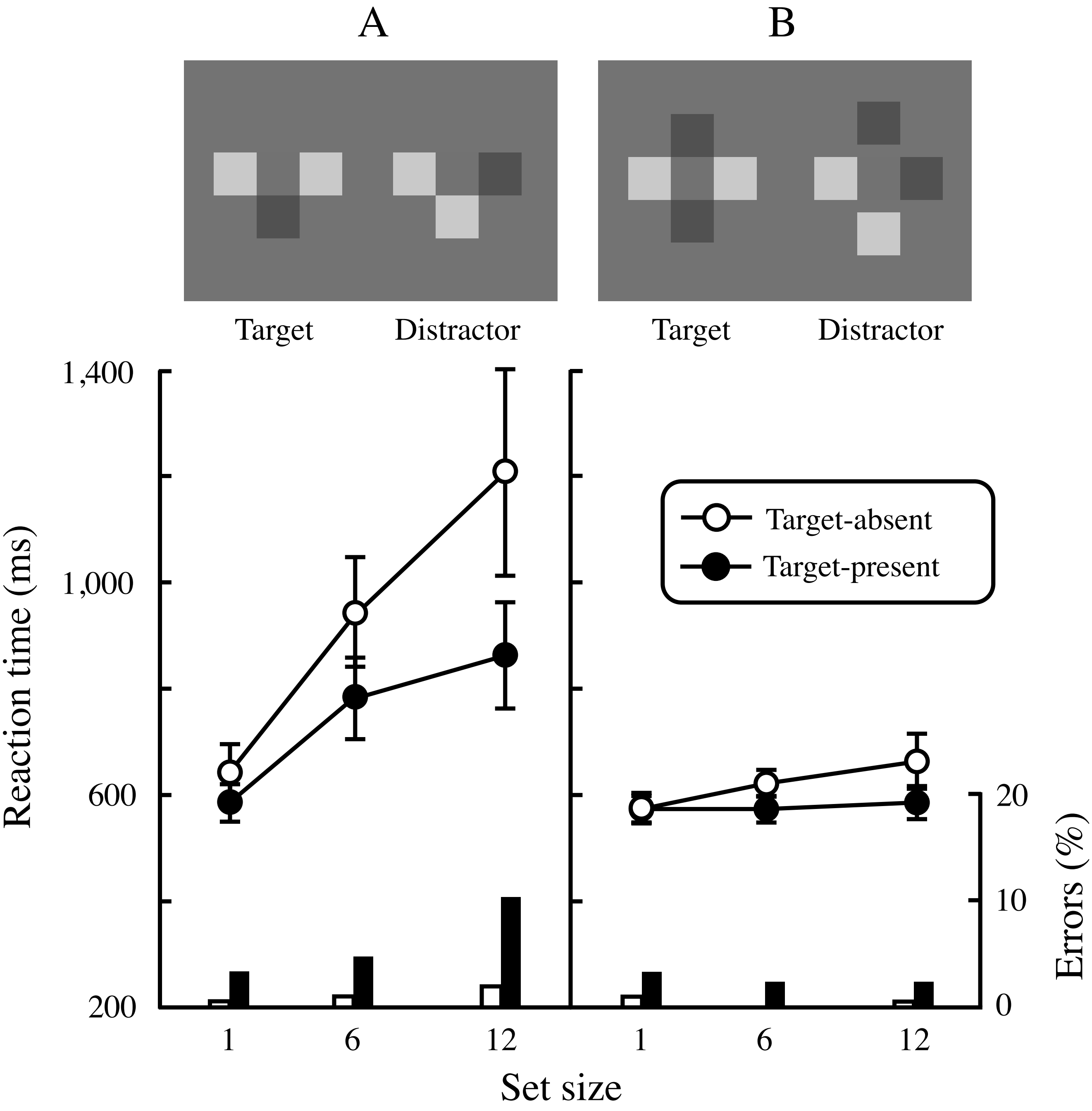
A

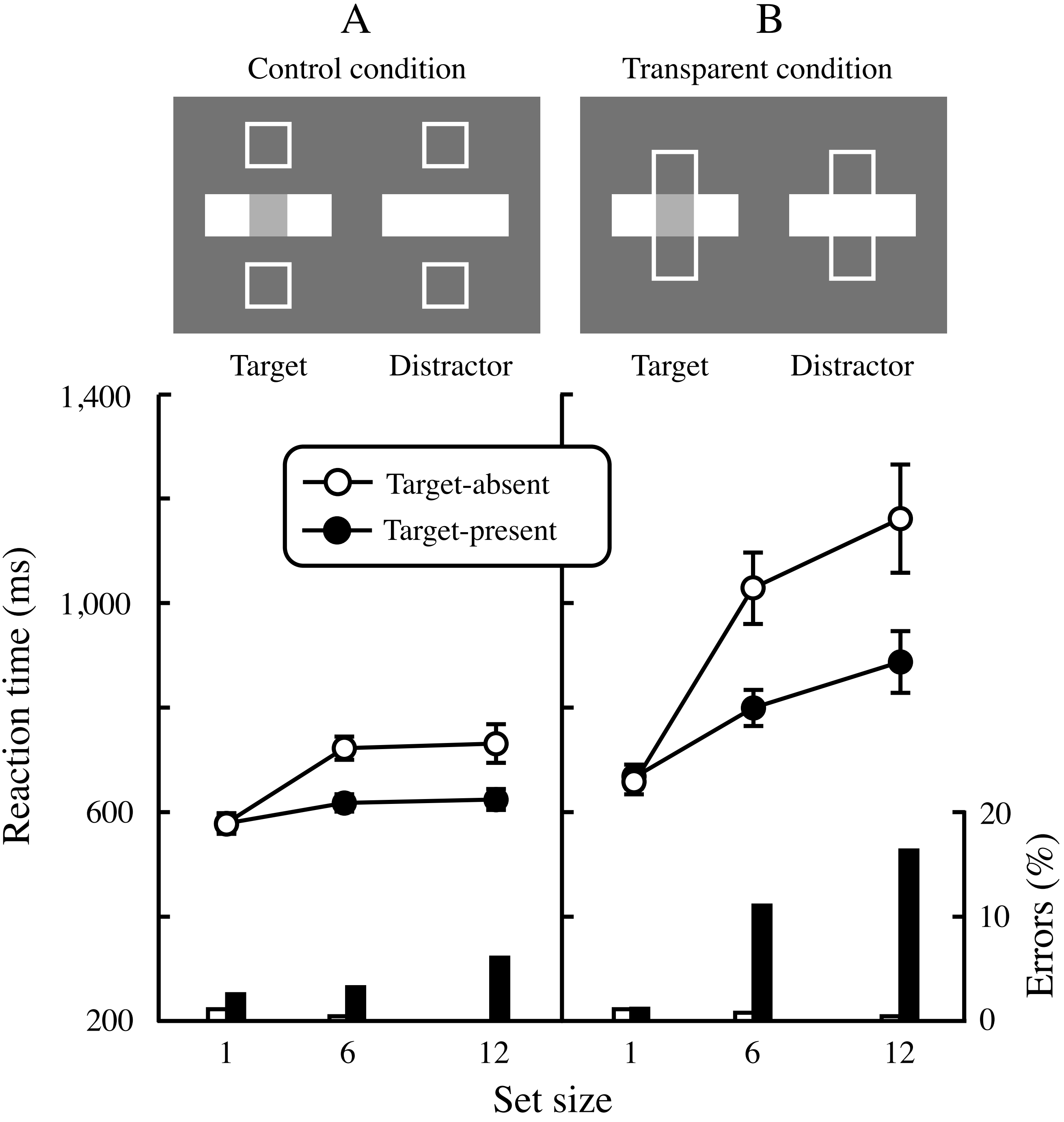


B




7
6
5
4
3
2
1
Transparency rating
Target
Distractor
Control
Transparent
Condition


A
B
Target
Distractor
Target
Distractor
1,400
1,000
600
200
Reaction time (ms)
Target-absent
Target-present
20
10
0
Errors (%)
1
6
12
1
6
12
Set size


A
Control condition
B
Transparent condition
Target
Distractor
Target
Distractor
1,400
1,000
600
200
Reaction time (ms)
Target-absent
Target-present
20
10
0
Errors (%)
1
6
12
1
6
12
Set size