Between-object superiority and the effects of preview on object-based attention in occluded objects

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Between-object Superiority and the Effects of Preview on
Object-based Attention in Occluded Objects

by

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Abstract

Object-based attention accounts assume that visual attention selects one object at a time and more efficiently processes properties belonging to the attended object relative to properties belonging to different objects. Within-object superiority (faster RTs and fewer errors for targets on the same object than for targets on different objects) supports object-based attention accounts. However, a contrasting effect, between-object superiority, has also been found. The present nine experiments were designed to distinguish between within-object and between-object superiority effects in objects with occlusion. The present results showed that between-object superiority can be obtained for occluded objects and that this effect is influenced by the probability that the targets appear on the same object or different objects and is eliminated by object preview. A whole-object matching theory was discussed to explain between-object superiority and to extend our understanding of object-based attentional selection.
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Introduction

Visual attention selects relevant information for further processing. Numerous studies have contributed to an understanding of the underlying mechanisms of attention by examining how and to what, attention is directed in the visual field. For example, studies on space/location-based attention (e.g., Downing & Pinker, 1985; Erickson & Yeh, 1985; Hoffman & Nelson, 1981; LaBerge, 1983; Posner, 1980) have found evidence that attention is allocated to a location in the visual environment, and information processing in the attended spatial area is facilitated. In contrast, studies on object-based attention (e.g., Behrmann, Zemel, & Mozer, 1998; Duncan, 1984; Egly, Driver, & Rafal, 1994; Shomstein & Yantis, 2002) have accumulated evidence in support of object-based attentional facilitation (i.e., multiple properties from one object are responded to faster and more accurately than are the same multiple properties when they occur across two objects) instead of space-based selection. In addition, the separate or complementary relationship between space-based and object-based attention has been explored (see Baylis & Driver, 1993; Buxbaum, Coslett, Montgomery, & Farah, 1996; Kim & Cave, 1995; Kramer, Weber, & Watson, 1997; Schendel, Robertson, & Treisman, 2001; Vecera, 1994, 1997; Vecera & Farah, 1994). Because an object always occupies a certain location, it is reasonable and easy to understand that space may mediate object-based selection under some circumstances. However, whether the two types of attention are independent or interactive, still remains an open question. That is, can attention be allocated to only one object or more than one object at a time?
Object-based attentional selection assumes that only a single object is attended to at a time, but space-based selection implies that one or more objects can be the focus of attention at the same time when they occupy the same location as can be the case for occlusion, in which one object spatially overlaps another object. Support for single-object selection comes from so-called within-object superiority (or same-object advantage, object-based benefit, or the same-object effect) which refers to faster and more accurate responding to features when they belong to the same object rather than to different objects (e.g., Duncan, 1984). In contrast, multiple-object selection is indicated by between-object superiority (or different-object advantages), which is faster or more accurate responding to features when they belong to different objects rather than to the same object (e.g., Davis, 2001; Davis & Holmes, 2005). The rest of this section will first review some studies on within-object superiority, then discuss the findings of between-object superiority, and finally propose a new account for between-object superiority and provide the motivation for and the goals of the present experiments.

Evidence for Within-object Superiority and Between-object Superiority

The argument regarding space-based attention and object-based attention focuses on the effect of distance and number of objects on responses to targets. According to space-based attention, targets separated by the same distance should be responded to equally quickly, whether those targets belong to the same object or different objects. If attention is object-based, targets on the same object should lead to faster responses relative to targets on different objects, even if targets are the same distance apart. Within-object superiority hence is examined under two conditions: equal distance and overlapping objects. Surprisingly, between-object superiority has also been found in the
equal distance condition, which is a challenge for both object-based and space-based attention.

**Within-object superiority in the two-rectangle paradigm (targets with equal distance).** Egly, Driver, and Rafal (1994) developed a new paradigm to investigate space-based and object-based attentional selection. As shown in Figure 1, two horizontal or vertical rectangles served as 2 objects in the visual display. The distance between two ends within a rectangle is equivalent to the distance between two adjacent ends of different rectangles. On each trial, two rectangles (either horizontal or vertical) with a fixation in the center of the display were presented, then one end of one rectangle was brightened briefly and followed by the target (a square filled in one end of the rectangle). The task was to press one single button whenever a target was detected at any of four ends of the two rectangles and withhold responses on catch trials for which no target appeared. The target was at the valid-cue location on 75% of the trials, invalid-same object on 12.5% of the trials, and invalid-different object on 12.5% of the trials. No target was presented at the rectangle end that is diagonal to the cued location. The typical cuing effect (faster responses at the cued location than the uncued location) was found. More importantly, responses were faster in the invalid-same object condition than the invalid-different object condition. Egly, Driver and Rafal (1994) concluded that the additional cost of shifting attention between objects indicated an object-based component in covert orienting. Lamy and Egeth (2002) claimed to provide evidence that a shift of attention is a prerequisite for object-based selection. In their first experiment, participants performed a same/different matching task for two simultaneously presented squares that had the same or different sizes. No object-based advantage was obtained when attention had to
be divided between two targets (i.e., no shifting attention from one target to another target). Because two targets were presented at the same time and the task was to identify whether the two targets are the same or different, Lamy and Egeth (2002) assumed that participants had to attend to both targets to perform the task so that no attention shift occurred. However, because participants’ eye movements were not monitored, it is possible that participants attended to one target and then shifted attention to the other target.

Marino and Scholl (2005, Experiment 2) adopted the procedure used in Lamy and Egeth’s (2002) Experiment 1 to explore further object-based selection for two simultaneously presented targets. In this procedure, two objects (either two rectangles or two pairs of parallel longer lines) first appeared on the screen for 1000 ms, and then the targets (i.e., brightened segments; see Figure 3) were presented for 300 ms and were masked. The task was to determine whether the longer line(s) or the rectangle(s) had the same or different number of brightened segments (targets) at its (their) ends. There was no precue or post-cue in this procedure. Also, the brightened segments could appear at any end of the rectangle or pair of parallel lines. Hence, participants presumably had to attend to the whole display area in order to do the task. Compared to the cuing method, this procedure is a better control of shifting attention. Still, the same-object advantage was obtained for both rectangles and parallel lines. Note that, for the same responses, there are 2 brightened lines in the same/within-object condition and 4 brightened lines in the different/between-object condition. The number of brightened lines is confounded with same vs. different objects. This might be a problem for their conclusion that a same-object advantage occurred. This confound was eliminated in the present experiments by
using rectangle- and triangle-shaped notches as targets.

**Between-object superiority in the two-rectangle paradigm (targets with equal distance).** Between-object (different-object) superiority refers to the fact that two properties are responded to faster and more accurately when they belong to two different objects than when they belong to the same object, with distance between the two properties controlled. Cepeda and Kramer (1999) reported 3 experiments in which between-object (or different-object) superiority was observed instead of within-object superiority. In Experiments 1 and 3, two wrenches were presented on each trial for 56 ms. Observers were instructed to perform a same/different matching task. Figure 4 shows an illustration of match or mismatch trials in either same-object condition or different-object condition. There is a subtle difference (rounded vs. rectangular open ends) on mismatch trials. Between-object superiority was significant for both matching and mismatching responses, but the matching response produced a greater effect as compared to the mismatching responses. Some participants reported after the experiment that, given the difficulty in performing the task, they adopted a strategy of translating the two wrenches laterally or vertically to overlap the two to-be-matched properties. Based on those subjective reports, Cepeda and Kramer assumed that between-object superiority might be produced by strategies such as object translation (superimpose two images) and mental rotation.

Cepeda and Kramer (1999) implied that attention could select more than one object at the same time, but they did not explicitly discuss the issue of how many objects can be selected. Davis and colleagues (Davis, Driver, Pavani, & Shepherd, 2000; Davis, Welch, Holmes, & Shepherd, 2001) posed the question of number of objects to which
attention can be distributed. If within-object superiority is truly caused by attention selecting only one object, then within-object superiority should be obtained when comparing a within-object condition with a between-object condition. In a match/mismatch task, they found no difference in mean reaction times between the two conditions (within vs. between). These results indicate that attention can select more than one object at a time.

**Davis and Holmes’ (2005) Criteria for Obtaining Within-object Superiority**

Based on a brief review of some previous studies that found a same-object advantage, Davis and Holmes (2005) discussed some common elements which they think are responsible for the same-object effect. The common aspects were listed as the *use of unfilled outline stimuli, the use of overlapping stimuli, extensive pre-exposure of the objects, and the number of intervening luminance edges*. Davis and Holmes then concluded that “Together, these results suggest that only when objects are either pre-exposed, or unfilled outlines (or possibly when they overlap) same-object benefits are always present. When filled, nonoverlapping, nonpre-exposed objects are employed, same-object costs are found.” (p. 823) Four experiments were conducted to provide evidence that absence of one of these four common elements would eliminate same-object benefit and produce between-object advantage. In Experiment 3, filled, separate objects that had the same number of intervening edges in both the same-object and different-object conditions (shown in Figure 5) were used with two objects following a fixation. A robust between-object superiority was observed which supported Davis et al.’s (2005) argument regarding the conditions needed to yield between-object superiority. However, the overlapping vs. nonoverlapping objects criterion was not examined by
Davis et al. (2005).

**Investigations of Within-object Superiority in Superimposed or Occluded Objects**

Object-based attentional selection in occlusion was first explored by Behrmann, Zemel, and Mozer (1998). Figure 6 illustrates the stimuli used in their Experiments 1a and 2a. The participants’ task was to judge whether the number of bumps on the two ends of any of the rectangles was the same or different. The two columns on the left were X displays in Experiment 1a, and the two columns on the right were V displays in Experiment 2a. Three rows represent each one of the three conditions: the within-object condition (with targets on the unoccluded object), the different-object condition (or two-object condition, with targets on two different objects), and the occlusion condition (with targets on the occluded object). Note that, targets were on the same object in both the within-object condition and the occlusion condition. The same pattern of results was observed across X and V display types. That is, responses to the within-object condition did not differ from the occlusion condition, but were faster relative to responses to the targets in the different-object condition. Hence, the same amount of same-object advantage was obtained for both the unoccluded object and the occluded object.

Behrmann et al.’s (1998) results of equivalent same-object effects for the unoccluded object and the occluded object can be interpreted in several ways. Firstly, the effect could be attributed to amodal completion which leads to the perception of the partly occluded objects as whole and complete, because occluded and unoccluded objects would have the same representation in memory after amodal completion. However, there are two reasons to challenge that interpretation. As argued by Saiki (2000), amodal completion is phenomenologically different for the X displays in Experiment 1a and the
V displays in Experiment 2a (i.e., the occluded X displays have a stronger impression of occlusion, as compared to the occluded V displays). Yet the two displays yielded the same effect. Also, amodal completion takes as long as 200 ms (Sekuler & Palmer, 1992).

Secondly, the effect could be caused by the co-linearity of bumps in X displays as discussed by Behrmann et al. (1998), because bumps are located co-linearly in the within-object and the occlusion conditions but not in the different-object condition. Obviously, V displays successfully eliminated the co-linearity account. However, V displays introduce a new confounded variable, symmetry (Saiki, 2000). The match stimuli are symmetrical in the within-object and the occlusion conditions but asymmetrical in the different-object condition. Hence, the equivalent within-object effects for nonoccluded and occluded objects may have been produced by collinearity for the X displays and by symmetry for the V displays.

Saiki (2000) examined the symmetry account in V displays. Experiment 1 was conducted to replicate the basic findings of Behrmann et al. (1998) by using the same set of V displays. Unfortunately, the same-object advantage in the within-object and occlusion conditions over the different-object condition was only obtained for the “same” responses. A different-object benefit was found for “different” responses. Also, the overall object effect (averaged across “same” and “different” responses) failed to reach statistical significance. Experiment 2a tested the symmetry effect by directly comparing the symmetrical V displays in Behrmann et al. (1998) with asymmetrical V displays. In the asymmetrical V displays, one arm of the V shape that had two targets on the ends was shortened. The results showed the different-object benefit only for the occluded object in the symmetry condition and no effect in the asymmetry condition. The asymmetrical
objects did eliminate the same-object advantage of the single and the occluded object over different objects. However, there was no same-object advantage in the symmetrical condition, either. According to Behrmann, Zemel, and Mozer (2000), symmetry may play an important role in the object-based selection, but it is not the reason for the same-object advantage. Moreover, the symmetry account also cannot explain the object-based effects in X displays in Behrmann et al. (1998), because X objects are not symmetrical in the within-object and occlusion conditions but they are symmetrical in the different-object condition.

**Potential Probability Effects on Within-object Superiority**

Behrmann et al. (1998, 2000) obtained equivalent same within-object superiorities for the modal-shape object and for the occluded object, but Saiki (2000) failed to replicate Behrmann et al.’s (1998, 2000) basic findings in V displays. The problem with Behrmann et al.’s (1998, 2000) stimuli (i.e., X displays and V displays) is that several confounding variables were not appropriately controlled. Besides co-linearity and symmetry, there was a probability confound in Behrmann et al. (1998). The number of trials in each of the three conditions (the within-object, the occlusion, and the different-object conditions) was perfectly equated. However, the two targets are presented on the two ends within the same object in two conditions (the within-object and the occlusion conditions) and on the two ends belonging to different objects only in one condition. Thus, equating the number of trials in each condition results in the two targets being on the same object on 2/3 the trials and on different objects on 1/3 of the trials. Findings from Shomstein and Behrmann (2008), and Shomstein and Yantis (2004) suggest that trial probability influences attentional processes. Therefore, we need to
consider every possible confounding factor before concluding whether within-object superiority occurs in the occlusion condition.

It should be noted that in the spatial precuing task (Egly, Driver, & Rafal, 1994; Lamy & Eggeth, 2002), the manipulation of cue validity also results in a confound between same/different object and the probability of target location. Because the probability of the target appearing at the valid cue’s location is much higher than it appearing in the invalid cue’s location (e.g., 75% vs. 25% for valid cue and invalid cue in Egly, Driver, & Rafal, 1994; 80% vs. 20% in Lamy & Egeth, 2002), the cue and target necessarily appear in a same object on most of the trials and would rarely appear in different objects. This manipulation might encourage participants to attend to the cued object which leads to a faster response for the same-object miscued target than for the different-object miscued target.

The potential effect of the probability of the target appearing in the same object as the cue versus the object different from the cued object was directly tested in Shomstein and Yantis’ (2004) Experiment 2, the displays for which are presented in Figure 7. In the two-rectangle spatial cuing paradigm, the cue was valid on 50% of the trials. The target appeared in the invalid-cue location either on 41.7% of the trials (high-probability condition) or on 8.3% of the trials (low-probability condition). Half of the invalid high-probability/low-probability trials were same-object trials, and the other half were different-object trials. The task was to perform a T/L letter discrimination among nontargets (Fs with different orientations). Except for the overall validity effect (cuing effect), the results revealed a probability effect, with faster identification of the target in the invalid high-probability condition than in the invalid low-probability condition. The
same-object advantage was also found at short cue-to-target SOAs (e.g., 200 ms and 400 ms), but this advantage was not influenced by probability. Similar results of independent probability effects and within-object superiority were replicated in Experiment 1 (unfilled outline objects) and Experiment 3 (objects filled with red color) in another study conducted by Shomstein and Behrmann (2008).

According to Shomstein et al. (Shomstein & Behrmann, 2008; Shomstein & Yantis, 2004), the probability effect indicates the influence of attentional priority to the cued object. High probability leads to high priority to the unattended locations within an attended object. Therefore, attentional prioritization is responsible for the object-based selection effect. Following Shomstein et al.’s rationale, the invalid low-probability condition should have yielded a smaller within-object superiority relative to the invalid high-probability, because no priority occurs in the low-probability condition. However, there was no interaction between probability and object in the results. In the design of Shomstein and Yantis (2004), the target appeared almost equally often in the same object (58.3%, with 50% on valid trials and 8.3% on invalid trials) or different objects (41.7%) on both the invalid low-probability and same-object trials and the invalid high-probability and different-object trials (41.7%). On the contrary, the target would appear in the same object (91.7%, with 50% on valid trials and 41.7% on invalid trials) much more often than in different objects (8.3%) on both the invalid high-probability and same-object trials and the invalid low-probability and different-object trials (see Figure 7). Therefore, the pre-cuing paradigm introduces a confound between probability and object conditions (within vs. between), because the target appeared in the same object on both valid and invalid trials but in different objects only on invalid trials.
Experiment 1

Previous research (e.g., Davis, 2001; Davis & Holmes, 2005; Egly, Driver, & Rafal, 1994; Shomstein & Yantis, 2002) found either within-object superiority or between-object superiority when using two separate rectangles. Although Davis et al. (2005) pointed out 4 common aspects shared by experiments that yielded within-object superiority and assumed that within-object superiority should be obtained under those four criterial conditions and between-object superiority should be obtained otherwise, they only examined one of these criterial conditions (filled object) but not the others. Besides the four criteria proposed by Davis et al. (2005), there is another shared factor in experiments that yielded within-object superiority: targets more often appeared within the same object than in different objects, especially in experiments that produced within-object superiority using the pre-cuing paradigm. Shomstein et al. (Shomstein & Behrmann, 2008; Shomstein & Yantis, 2004) argued that probability affects the distribution of attention. The same probability problem occurred in Behrmann et al.’s (1998) experiments. However, the effects of probability have never been directly investigated for the occluded objects used by Behrmann et al. (1998).

The first experiment of the present research was designed to investigate the potential effects of the probability of the targets appearing in the same vs. different objects in one of Davis et al.’s (2005) criterial conditions (occluded objects) for within-object superiority. If the significant within-object superiority is a robust effect, it should still be observed for occluded objects, which are more difficult to perceive than nonoccluded separate objects, when the probability of the targets appearing in the same vs. different objects are equated. Although Behrmann et al.(1998) reported equivalent
levels of same-object benefit for non-occluded and occluded objects, their conditions included several confounding factors, such as probability of targets appearing in same vs. different objects. That is, because there was an equal number of trials in each of the three conditions in Behrmann et al.’s experimental design, the two targets were on the same object on 2/3 of the trials (the within-object condition and the occlusion condition) and on different objects on 1/3 of the trials (the two-object condition). The confound of probability of targets appearing in same vs. different objects has also been involved in the pre-cuing paradigm (e.g., Egly, Driver, & Rafal, 1994; Lamy & Egeth, 2002). It is important to examine whether or not equal within-object superiority for both occluded and nonoccluded objects is still obtained when this confounded variable is eliminated.

There were four groups of participants created by a 2 (Target type: bumps vs. notches) x 2 (Same-Different Object Probabilities equated vs. confounded) design. The bumps were replaced by square-shaped and triangle-shaped notches (see Figure 8) because the task of matching the numbers of bumps may encourage counting and shifts of attention. That is, participants may have counted the number of bumps on one target then shifted attention to count the number of bumps on the other target, because it is impossible to count the numbers on both targets at the same time. The four groups in the design were the Notches/Same-Different Object Probabilities Equated group, the Notches/Higher Same-object Probability group, the Bumps/ Same-Different Object Probabilities Equated group, and the Bumps/Higher Same-object Probability group. This design allows us to determine if the within-object superiority observed by Behrmann et al. (1998) was due to the probability of targets appearing in same objects being higher than their appearing in different objects and/or to the task of encouraging participants to
“count” the bumps, which likely would have induced attention shifting, which would be less likely to occur when notch shapes rather than numbers are being compared. If Behrmann et al.’s (1998) finding of a same-object benefit was due to either of these variables in isolation, then it should occur in all but the Notches/Same-Different Object Probability Equated group, for which neither of these variables was present and perhaps a between-object superiority effect might even occur in that group. If Behrmann et al.’s (1998) finding of a same-object benefit was due to the conjunction of these two variables, then it should occur only in the Bumps/Higher Same-Object Probability group, with either no object effect or a between-object superiority effect occurring in the other three groups. If, however, Behrmann et al.’s (1998) finding of a same-object benefit was due to only one of the other variables alone, then it should occur in the two groups for which that variable was present, with either no object effect or a between-object superiority effect occurring in the two groups in which that variable was absent.

Methods

**Participants.** Ninety undergraduate students (22 in Group 1, 22 in Group 2, 23 in Group 3, and 23 in Group 4) from University at Albany, State University of New York participated in the four studies for course credits. No student participated in more than one group. All students reported to have normal or corrected-to-normal vision. They were separately tested in a dimly lit lab room during a session of about 30 minutes.

**Materials.** The stimuli were presented on a 17-inch screen with a PC-compatible computer running E-prime 1.2 that controlled the stimulus display and collected reaction times. Participants were seated at a distance of 65-70 cm from the computer screen. Figure 8 gives examples of the stimuli used for the Notches/Same-Different Object
Probabilities Equated group and the Notches/Higher Same-object Probability group and Figure 6, the left column (X display), illustrates the objects used for the Bumps/ Same-Different Object Probabilities Equated group, and the Bumps/Higher Same-object Probability group. These figures were drawn by Paint. Each of the two rectangles subtended 1.14 degrees of visual angle in height and 6.54 degrees in width. The objects were displayed in a 5.4 x 5.4 degrees area in the center of the screen. A plus sign served as a fixation and subtended 0.5 degrees of visual angle. Both the objects and the fixation were black line drawings that were presented on a white background.

**Procedure and Design.** The complete design was a 2 (Probability: Same-Different Object Probabilities equated vs. confounded) x 2 (Target type: bumps vs. notches) x 3 (Condition: same-object-nonocclusion, same-object-oclusion, and different-object conditions) x 2 (Response: “same” vs. “different”) mixed design with probability confound and target type as between-subjects variables and condition and response as within-subjects variables. Each participant was asked to sign the consent form before they were given instructions for the task. On each trial, the fixation (“+”) was presented for 1000 ms and followed by the objects which remained on the screen until a response was detected. For notches, matching was to be based on notch shape and for bumps, on whether or not the numbers of bumps were the same on the two targets (i.e., both had two bumps, or 3 bumps, or one had two and the other had three bumps). There were 32 trials in each of the two same-object conditions and 64 trials in the different-object condition in the Notches/Same-Different Object Probabilities Equated group and the Bumps/ Same-Different Object Probabilities Equated group. With the confound of probability of targets appearing in same vs. different objects in the Notches/Higher Same-object Probability
group and the Bumps/Higher Same-object Probability group, there were 32 trials in each of the three conditions. Participants were instructed to press the C key and comma key on the standard keyboard to respond to two same-shaped notches (or same number of bumps) and two different-shaped notches (different numbers of bumps). The mapping between the two response keys and the same/different response was counterbalanced. A “ding” sound occurred when participants made an incorrect response. Each participant was given a 32-trial practice block before the real experiment trials began.

Results

Data from the practice blocks were removed from the analysis. Only reaction times for correct responses from the remaining blocks were analyzed (overall accuracy 90%). The final analysis also excluded trials with a reaction time beyond 3 standard deviations of the means of each participant in each condition. These data trimming procedures removed 5.9% of the trials in the Notches/Same-Different Object Probabilities Equated group, 6.0% in the Notches/Higher Same-object Probability group, 6.0% in the Bumps/ Same-Different Object Probabilities Equated group, and 6.0% in the Bumps/Higher Same-object Probability. The significance level was .05, otherwise specified. The data from all cells in Experiment 1 are presented in Appendix A.

A 2 (Probability: equated vs. confounded) x 2 (Target type: notches vs. bumps) x 3 (Condition: same-object-nonocclusion, same-object-occlusion, and different-object) x 2 (Response: “same” vs. “different”) mixed design repeated measure ANOVA was conducted, with probability and target type as between-subjects variables and condition and response as within-subjects variables. Only significant effects and effects of central interest are reported. The analysis showed target type did not interact with other factors
(all $F$s < 1.56). Thus, Table 1 shows mean reaction times averaged over target type as a function of condition, response, and probability. There was a significant main effect of condition in the same direction for both RTs and errors, $F (2,172) = 5.62$, $p = .006$, $MSE = 1467.26$, $\eta^2 = .06$ and $F (2,172) = 6.28$, $p = .004$, $MSE = .001$, $\eta^2 = .07$, respectively. An overall between-object superiority (9 ± 9 ms and 0.8 ± 0.4 %) was obtained for only occluded objects in RTs, but for both occluded and unoccluded objects in errors. An overall between-object superiority was not found in either Behrmann et al. (1998) or Saiki (2000). Rather, Behrmann et al. (1998) found an overall within-object superiority and Saiki (2000) found within-object superiority for “same” responses and between-object superiority for “different” responses. There was also a main effect of response for both RTs and errors, $F (1,86) = 148.05$, $p = .000$, $MSE = 2192.94$, $\eta^2 = .63$ and $F (1,86) = 21.42$, $p = .000$, $MSE = .001$, $\eta^2 = .20$, respectively, but in opposite directions, indicating that “same” responses (689 ms) were 49 ± 8 ms faster than “different” responses (738 ms), but there were 1.1 ± 0.5% more errors for same than different responses, indicating a speed-accuracy trade-off. The interaction between probability and condition was significant for RTs but not errors, $F (2,172) = 3.73$, $p = .032$, $MSE = 1467.26$, $\eta^2 = .04$ and $F (2,172) = 1.08$, $p = .337$, $MSE = .001$, $\eta^2 = .01$, respectively, such that averaged over “same” and “different” responses, a 11 ± 9 ms within-object superiority was obtained only for nonoccluded objects with unequal probabilities (i.e., confound of probability of targets appearing in same vs. different objects was included) and a 18 ± 15 ms between-object superiority was obtained for occluded objects in the equal probability groups (i.e., probability confound was removed); a 0 ± 10 ms within-object superiority was obtained for occluded objects with unequal probabilities and a 5 ±
9 ms Between-object superiority for nonoccluded objects with equal probabilities \( F(2, 88) = 5.00 \) and \( F(2, 88) = 4.55 \), respectively. The probability x condition interaction is a new and important result of the present experiment in that it shows that an overall within-object superiority effect (averaged over “same” and “different” responses) occurs only for nonoccluded objects and only when the probability that targets appear in the same object is higher than the probability that they appear in different objects. Averaged over “same” and “different” responses, a between-object superiority effect occurs only for occluded objects and only when the probabilities that targets appear in the same vs. different objects are equated. However, these interactions are qualified by an interaction with response. The interaction between condition and response was significant for RTs but not errors, \( F(2, 172) = 8.85, p = .000, \) MSE = 746.89, \( \eta^2 = .09 \) and \( F(2, 172) = 2.37, p = .097, \) MSE = .001, \( \eta^2 = .03 \), respectively. This interaction was that there was a 20 ± 10 ms between-object superiority in the occluded object and a 6 ± 7 ms between-object superiority in the nonoccluded object for “same” responses, but a 12 ± 9 ms within-object superiority in the nonoccluded object and a 2 ± 11 ms within-object superiority for “different” responses \( F(2, 172) = 11.63 \) and \( F(2, 172) = 3.28 \), respectively. Saiki (2000) also reported an interaction between condition and response. However, Saiki observed a within-object superiority for “same” responses and a between-object superiority for “different” responses, which is opposite of what was observed here. Also, Saiki found equal within-object or between-object superiority effects for occluded and nonoccluded objects, whereas I found an occlusion difference. The experiment of Saiki (2000) also included the confound of probability of targets appearing more often on the same object than on different objects. There was also a significant 3-way interaction.
between condition, response, and probability for RTs but not errors, $F(2,172) = 3.04$, $p = .050$, MSE = 746.89, $\eta^2 = .03$ and $F(2,172) = .37$, $p = .69$, MSE = .001, $\eta^2 = .00$, respectively. When probability differences are confounded with within- and between-object conditions, there was an $18 \pm 11$ ms between-object superiority only for the occluded object in same responses and there was a $23 \pm 13$ ms and an $18 \pm 12$ ms within-object superiority for unoccluded and occluded objects, respectively, in different responses ($F = 7.86$ and $F = 9.23$, respectively). Most important, when the probability confound was eliminated, there was an $11 \pm 9$ ms and a $22 \pm 16$ ms between-object superiority for unoccluded and occluded objects, respectively, in same responses and no statistically significant effects in different responses ($F = 5.49$ and $F = 1.97$, respectively) (see Table 1).

**Discussion**

The most important results of the first experiment are the interaction between object condition and whether the probability of targets appearing in same vs. different objects was equated or higher in the same-object condition. That is, within-object superiority was obtained when probability confounding was involved, and between-object superiority was obtained when probability confounding was eliminated. It seems that probability confounding has an influence on obtaining within-object or between-object superiorities. These results are different from the findings of Behrmann et al. (1998) and Saiki (2000). Behrmann et al.’s (1998) experiment (X displays) yielded equal within-object superiority for both occluded and unoccluded objects and no interaction between object condition and response. The equal within-object superiority for both occluded and unoccluded objects was only found for different responses but not same
responses in the present experiment. Between-object superiority for same responses is a completely new result. Saiki (2000) found within-object superiority for same responses and between-object superiority for different responses in V displays, which does not replicate the results of Behrmann et al.’s (1998) Experiment 3, either.

As in Experiment 1 of Saiki (2000), the present the Bumps/Higher Same-object Probability group used the same stimuli and procedure as in Behrmann et al.’s (1998) first experiment. However, Behrmann et al.’s (1998) finding of equal within-object superiority was only replicated in the present experiment when participants performed different responses but not same responses. An interaction between object condition and response was also obtained by Saiki (2000) though, as discussed earlier, it was different from the one observed here. At this point, there is no obvious account for why a within-object vs. between-object superiority effect would depend on “same” vs. “different” responses. This issue will be discussed in the General Discussion section based on the data observed in the following experiments. However, the important feature of the current results was that when the probabilities that the targets appear on the same vs. different object are equated, one obtains a between-object superiority effect (for “same” responses) for both occluded and non-occluded objects and obtains no evidence of a within-object superiority effect. For these stimuli, a within-object superiority effect was obtained only when the probability that the targets appeared on the same object was greater than the probability that the targets appeared on different objects (and even then, only for “different” responses).

Experiment 2

Prior studies using both X displays and V displays introduced multiple
confounding factors, such as colinearity, symmetry, and trial probability as noted in Behrmann et al. (2000), Saiki (2000), and here. The results of within-object superiority with probability confounding and between-object superiority without probability confounding obtained in the present experiments indicate that there is an effect of probability on object-based selection. Besides the probability confounding, depth introduced by occlusion is also confounded with same/different–object conditions in Behrmann et al.’s (1998) experiments. As shown in Figure 6, two targets are on the same depth level when they appear within the same object in the within-/same-object conditions, whereas two targets are on different depth levels when they appear on different objects in the between-/different-object condition. Atchley and Kramer (2001) concluded that depth level did not influence within-object superiority in 3D stimuli, but it is not clear whether depth level has an effect on object-based selection when 2D objects are used.

Atchley and Kramer (2001, Experiment 1) investigated object-based attention in depth, but they employed stimuli in 3-dimensional space. Their computer generated object displays that resembled “pipes attached to a surface” and their four conditions are illustrated in Figure 9. Participants were instructed to detect the presence of one or two targets (green dots). The same-object advantage was significant in both the same depth condition and different depths condition. A greater same-object advantage was found at different depths than at the same depth. Different depths also increased the reaction times when targets were on different objects. These results showed that depth boosted within-object superiority in 3D space. However, depth in 3D space may differ from depth in occlusion, because there are more depth cues in 3D space than in occlusion which is
Experiment 2 was designed to examine the effect of target depth level on object selection and to investigate whether the between-object superiority obtained for “same” responses for occluded and nonoccluded objects when the probabilities that the targets appear on the same vs. different objects are equated can be replicated by using a new set of occluded objects for which the depth of the targets was varied. Four display types were used in the current experiment, either with targets presented on the same depth level (e.g., Figure 10 A and B) or on different depth levels (e.g., Figure 10 C and D), or with targets presented on the unoccluded objects or the occluded objects. If depth has an influence on object attention, a significant interaction between depth and object condition should be obtained. Based on the results of the first experiment (i.e., unequal probabilities of targets that appear in the same vs. different objects affect object-based selection), targets in the current and the following experiments had equal probability in both same- and different-object conditions.

Methods

Participant. Thirty three new undergraduates from the same population as in Experiment 1 participated for course credits. Data from three participants were excluded from the final analysis because their accuracy rates were below 90%.

Materials. The stimuli were presented as in Experiment 1. As shown in Figure 10, each type of display consisted of three rectangles, two darker grey ones with RGB (128, 128, 128) and lumination of 120, and one lighter grey one with RGB (192, 192, 192) and lumination of 181. For the horizontal stimuli (two grey bars were horizontal and the light grey bar was vertical) illustrated in Figure 10, each of the two grey rectangles subtended
5.46 and 1.04 degrees of visual angle in width and height, respectively. The light grey rectangle had a width of 1.04 degrees and a height of 7.43 degrees of visual angle. The width and height were reversed in the vertical stimuli (two grey bars were vertical and the light grey bar was horizontal). The distance between the two grey rectangles was the same as the width (of the horizontal stimuli) or height (of the vertical stimuli) of the rectangle. As shown in Figure 10, the light grey rectangle was in back of the two grey ones in the both-no-occlusion condition, in front of the two grey ones in the both-occlusion condition, and in back of one of the two grey ones and in front of the other grey ones in the single-no-occlusion and single-occlusion conditions. Targets were always presented at two equidistant ends of the darker grey rectangles. No target ever appeared on the light grey rectangle. The target was constructed by removing a square-shaped or a triangle-shaped area (0.41 x 0.41 degrees) at the two very ends of the grey rectangles. All stimuli were presented against a black background.

**Procedure and Design.** Unless otherwise noted, the procedures were the same as those in Experiment 1. After arriving in the testing room, each participant was asked to sign the consent form before they were given instructions about the task. On each trial, the fixation (“+”) was presented for 1000 ms and followed by the objects which remained on the screen until a response was made. There were 32 trials in each of the four types of display, for 128 trials total with equal probabilities of targets appearing in same vs. different objects. Participants were instructed to press the C key and comma key on the standard keyboard to respond to two same-shaped notches (or same number of bumps) and two different-shaped notches (different numbers of bumps). The mapping between the two response keys and the same/different response were counterbalanced. A “ding”
sound occurred when participants made an incorrect response. Each participant was given a 32-trials practice block before the experimental trials began.

**Results and Discussion**

Data were treated as in Experiment 1. The data trimming procedures removed 2.7% of the trials. The data from all cells in Experiment 2 are presented in Appendix B.

A 2 (Depth: same vs. different) x 2 (Target location: occluded vs. unoccluded objects) x 2 (Object: within vs. between) x 2 (Response: “same” vs. “different”) repeated measures ANOVA was performed on mean reaction times and errors. Only significant effects (p< .05) and effects of central interest are reported. The main effect of object was significant for RTs but not errors, $F(1, 29) = 18.24, p = .000, \text{MSE} = 3379.37, \eta^2 = .39$ and $F(1, 29) = 3.72, p = .064, \text{MSE} = .009, \eta^2 = .12$, respectively, indicating an overall 22 ±11 ms between-object superiority. As in Experiment 1, there was a main effect of response for both RTs and errors, but in opposite directions, $F(1, 29) = 25.70, p = .000, \text{MSE} = 10425.21, \eta^2 = .47$ and $F(1, 29) = 6.22, p = .019, \text{MSE} = .009, \eta^2 = .18$, respectively, such that ”same” responses were 47 ± 19 ms faster than “different” responses but 2.2 ± 1.8% more error prone. The interaction between object and response was significant for both RTs and errors, $F(1, 29) = 10.90, p = .003, \text{MSE} = 4524.70, \eta^2 = .27$ and $F(1, 29) = 7.84, p = .009, \text{MSE} = .009, \eta^2 = .22$, respectively. There was a 43 ± 17 ms (4.2 ± 3.6%) between-object superiority ($F = 23.93$ for RTs; and $F = 5.76$ for errors) for “same” responses but no statistically significant effect for “different” responses (3 ± 14 ms, $F =.10$ for RTs; and 0.7 ± 0.7%, $F = 1.90$). The interaction between object and response replicated the results of Experiment 1 (without the probability confounding). Because the main effects of depth and target location failed to reach
significance and these two variables did not interact with either object or response (all Fs < 2.65), mean RTs averaged over the four types of displays are shown in Table 2 as a function of object and response.

Between-object superiority was replicated in Experiment 2 with possible confounding factors such as probability, depth, colinearity etc. eliminated. For the occluded object, some elements are obscured and those visible parts are often spatially distant and discontinuous. The processing of amodal completion occurs along with the formation of a representation of the occluded object. Amodal completion may not occur for all participants or on all trials. When there is no amodal completion, the occluded object is perceived as separate objects, which may explain why between-object superiority may have been eliminated in the both-occluded objects condition.

If amodal completion influences attentional selection, then different results should be observed in conditions that either encourage or discourage amodal completion. Experiment 3 investigated the effect of amodal completion on attentional selection by mixing displays (see Figure 10 C and D) of single occluded objects with either displays of unoccluded objects or displays of separate objects as illustrated in Figure 11. The assumption was that participants will employ amodal completion more when the single occluded object is mixed with unoccluded objects than when it is mixed with separate objects. If this is the case, a between-object superiority should be obtained in the block that encourages amodal completion but not the block that discourages amodal completion.

**Experiment 3**

**Methods**

*Participants.* Twenty eight new undergraduates from the same population as in
Experiment 1 participated for course credits. The data from four participants were excluded in the final analysis, because the accuracy rates were below 90%.

**Materials.** The stimuli used in the current experiment were similar to those used in Experiment 2. There was one change: the both-occlusion condition was replaced by the separate-objects condition. Figure 11 gives an illustration of the separate objects. The whole display consisted one large bar and two small bars. The large bar was in the same size as the grey rectangles in the other three conditions. The gap between the two small bars was formed by removing an area with the same width as the light grey rectangle. Two targets were presented either at the two ends of the large bar or at the outer end of each of the two small bars in the within-object condition, and at one end of the large bar and one outer end of the small bar in the between-object condition.

**Procedure and Design.** The same procedure as those of Experiment 2 was employed. However, in the current experiment, the single-no-occlusion and the single-occlusion conditions were randomly intermixed either with the both-no-occlusion condition or with the separate-object conditions in separate blocks. The order of the two blocks was counterbalanced between participants. Participants received practice trials before each block.

**Results and Discussion**

Data were treated as in prior experiments. The data trimming procedures removed 5.1% of the trials in the block with the both-no-occlusion object and 4.5% of the trials in the block with the separate objects. The data from all cells in Experiment 2 are presented in Appendix C and Appendix D.

Although separate analyses were conducted for each of the two blocks, the results
of the block with single-occluded object intermixed with separate objects are not reported here because the current experiment was designed to examine whether the amodal completion process in the single occluded object was affected by the contextual factor that encourages or discourages amodal completion and whether the results of Experiment 2 could be replicated. A 3 (Display type: both-no-occlusion, single-no-occlusion, and single-occlusion) x 2 (Object: within vs. between) x 2 (Response: same vs. different) repeated measures ANOVAs were performed on mean reaction times and accuracy, respectively, for the trials in the block of encouraging amodal completion. Only significant effects and effects of central interest are reported. The main effect of display type was significant for RTs but not errors, $F(2, 46) = 5.15, p = .016, \text{MSE} = 3374.03, \eta^2 = .18$ and $F(2, 46) = 1$, respectively, indicating that RTs were $20 \pm 11$ ms and $21 \pm 18$ ms in the both-no-occlusion and single-no-occlusion conditions than in the single-occlusion condition. There was a significant main effect of object for both RTs and errors, $F(1, 23) = 25.81, p = .000, \text{MSE} = 2744.57, \eta^2 = .53$ and $F(1, 23) = 5.74, p = .030, \text{MSE} = .001, \eta^2 = .19$, respectively, indicating a $31 \pm 12$ ms or $1.0 \pm 0.9\%$ overall between-object superiority. There was also a significant main effect of response for both RTs and errors, but in opposite directions, $F(1, 23) = 8.53, p = .008, \text{MSE} = 8663.49, \eta^2 = .27$ and $F(1, 23) = 12.72, p = .002, \text{MSE} = .001, \eta^2 = .36$, respectively, indicating that “same” responses were $32 \pm 23$ ms faster or $1.5 \pm 0.7\%$ less accurate than “different” response. The interaction between object and response was significant for both RTs and errors, $F(1, 23) = 21.69, p = .000, \text{MSE} = 2064.40, \eta^2 = .49$ and $F(1, 23) = 13.74, p = .001, \text{MSE} = .001, \eta^2 = .37$, respectively. For “same” responses, a $56 \pm 20$ ms (or $2.5 \pm 1.5\%$) between-object superiority was obtained ($F(1, 23) = 33.66, and F(1, 23) = 11.78,$}
respectively); for “different” responses, a 6 ± 13 ms (or 0.5 ± 0.9%) nonsignificant between-object superiority was obtained ($F$s = 1). No other effects were significant (all $F$s <= 1). Table 3 shows the mean RTs and errors as a function of object and response.

Also, the trials in the single-no-occlusion and the single-occlusion conditions in the two blocks were subjected to a 2 (Context: separate-objects vs. both-no-occlusion) x 2 (Display type: single-no-occlusion vs. single-occlusion) x 2 (Object: within vs. between) x 2 (“same” vs. “different”) repeated measures ANOVA. Only significant effects and effects of central interest are reported. There was a significant main effect of display type for errors but not RTs, $F (1, 23) = 8.15, p = .009$, $MSE = .001, \eta^2 = .26$ and $F (1, 23) = 4.11, p = .054$, $MSE = 3705.25, \eta^2 = .15$, respectively, such that fewer errors (0.8 ± 0.5%) were made when targets were presented on the occluded object than on the unoccluded object. There was a main effect of object for both RTs and errors, $F (1, 23) = 23.63, p = .000$, $MSE = 5039.05, \eta^2 = .51$ and $F (1, 23) = 5.83, p = .024$, $MSE = .003, \eta^2 = .20$, respectively, indicating a 35 ± 15 ms or 1.4 ± 1.3% overall between-object superiority. The main effect of response was significant for both RTs and errors, $F (1, 23) = 12.65, p = .002$, $MSE = 9676.11, \eta^2 = .36$ and $F (1, 23) = 15.50, p = .001$, $MSE = .003, \eta^2 = .40$, respectively, such that “same” responses were 35 ± 21 ms faster and 2.0 ± 1.0% less accurate than “different” responses. The interaction between object and response was significant for both RTs and errors, $F (1, 23) = 20.23, p = .000$, $MSE = 3470.33, \eta^2 = .47$ and $F (1, 23) = 5.50, p = .028$, $MSE = .003, \eta^2 = .19$, respectively. As in the prior experiments, there was a 62 ± 19 ms ($F = 48.31$) or 2.8 ± 2.3% ($F = 6.22$) between-object superiority for “same” responses, whereas for “different” responses, between-object superiority was not significant (8 ± 20 ms, $F < 1$; 0.1 ± 0.7%, $F = 1$).
Table 4 displays mean reaction times and errors as a function of object and response.

Amodal completion was either encouraged or discouraged by mixing the single occluded objects with unoccluded and whole objects or separate objects in Experiment 3. The result of between-object superiority for “same” responses but not “different” responses in Experiment 2 was replicated the current experiment. If amodal completion contributes to object-based selection (as discussed in Behrmann et al. 1998), then within-object superiority should be produced by the condition where the occluded objects were mixed with unoccluded objects (amodal completion encouraged) but no effect or between-object superiority should be obtained by the condition in which the occluded objects were mixed with separate objects (no amodal completion). This predicted pattern of results did not occur in the current experiment ($F < 1, p = .78$ for the 3-way interaction between context, display type, and object). A statistically significant between-object superiority was obtained in both contexts (with/without amodal completion), especially for same responses. The finding of between-object superiority for same responses replicated the result in Experiment 2. No effect of amodal completion on attentional selection was obtained. One reason for the absence of a context effect may be that amodal completion was not influenced by mixing occluded objects with whole or separate objects.

According to Sekuler and Palmer (1992), amodal completion takes as long as 200 ms to finish. If the occluded objects are pre-exposed for 200 ms or longer, amodal completion should be finished and the occluded objects should be perceived as whole objects. Moreover, object preview was proposed by Davis and Holmes (2005) as one of the four contributors to same-object benefit. Also, Shomstein and Behrmann (2008) argued that object preview helps to establish a robust object-based representation given
sufficient exposure duration, and that the established object-based representation is the unit of attentional selection. On the basis of previous discussion about the influence of object preview, the presence of object preview with long duration should produce within-object superiority, and absence of object preview should yield no effect or between-object superiority. No previous studies have ever manipulated the presence and the absence of object preview at the same time. Three experiments (Experiments 4-6) in the current research compared the influence of presence and absence of object preview both between subjects and within subjects to provide a clear picture of how object preview affects object-based attention. Experiment 4 used the same stimuli and the similar procedure as in Experiment 2, except that the target display was preceded by object preview on every trial.

Experiment 4

Methods

Participants. Thirty three new undergraduates from the same population as in Experiment 1 participated for course credits. Data from three were excluded from the final analysis, because the accuracy rates were below 90%.

Materials. The same stimuli were employed in the current experiment as in Experiment 2, except that a display of three bars without targets was included as the object preview. An example of events on a trial is shown in Figure 12.

Procedure and Design. The procedure was the same as in Experiment 2, except for one change in the event sequence of each trial. In the current experiment, every trial began with a 1000 ms fixation, and then the display of three bars without targets was presented for 250 ms and followed by the targets.
Results and Discussion

The data trimming procedures removed 4.6% of the trials. The data from all cells in Experiment 2 are presented in Appendix E.

A 4-way repeated measure ANOVA was conducted with depth (same vs. different), target location (occluded vs. unoccluded objects), object (within vs. between), and response (“same” vs. “different”) as within-subjects variables. Only significant effects and effects of central interest are reported. The main effect of response was significant for both RTs and errors, $F(1, 29) = 11.33$, $p = .002$, $MSE = 6971.13$, $\eta^2 = .28$ and $F(1, 29) = 16.37$, $p = .000$, $MSE = .002$, $\eta^2 = .36$, respectively, such that “same” responses were $25 \pm 15$ ms faster and $1.4 \pm 0.7\%$ less accurate than “different” responses. There were no other significant main effects or interactions. Most critically, the main effect of depth, the main effect of target type, the main effect of object, and the Object x Response and other 2-way interactions, and the 3-way and 4-way interactions were not significant for either RTs or errors (all $Fs < 2.22$).

The between-object superiority effect obtained in Experiment 2 was eliminated by the presence of object preview in Experiment 4, although the same stimuli and procedures were used. It seems that object preview affects between-object superiority. However, two different groups of participants were recruited for Experiments 2 and 4. Hence, individual difference may contribute to the elimination of the effect. Experiments 5 and 6 manipulated absence vs. presence of object preview within subjects such that individual difference was controlled. Experiment 5 combined Experiments 2 and 4 and used the same stimuli and procedure as in those two experiments. That is, object preview was absent in one block (as in Experiment 2) and present in the other block (as in
Experiment 4). Experiment 6 used only the both unoccluded and both occluded objects (A and B in Figure 10) and added the two-rectangle display to investigate whether or not the preview effect would generalize to conditions with no occlusion involved.

**Experiment 5**

**Methods**

*Participants.* Twenty three new undergraduates from the same population as in Experiment 1 participated for course credits. Data from two participants were excluded in the final analysis because their accuracy rates were below 90%.

*Materials.* The same stimuli were employed in the current experiment as in Experiment 2, except that a display of three bars without targets was included as the object preview (as in Experiment 4).

*Procedure and Design.* The presence or absence of object preview was manipulated across blocks within subjects. On trials with object preview, the procedure was the same as in Experiment 4. On trials without object preview, the procedure was the same as in Experiment 2. There were two separate blocks: the preview-absence block (with the same trial procedure as Experiment 2), and the preview-presence block (with the same trial procedure as Experiment 4). The order of the two blocks was counterbalanced between participants.

**Results and Discussion**

The data trimming procedures removed 3.7% of the trials. The data from all cells in Experiment 2 are presented in Appendix F.

A 5-way ANOVA was computed with preview (absence vs. presence), depth (same vs. different), target location (occluded vs. unoccluded), object (within vs.
between), and response (same vs. different) as factors. All variables were within subjects.

Only significant effects and effects of central interest are reported.

The main effect of preview was significant for RTs but not errors, \( F(1, 20) = 36.39, p = .000, \text{MSE} = 24918.95, \eta^2 = .65 \) and \( F(1, 20) = 2.25, p = .149, \text{MSE} = .002, \eta^2 = .10 \), respectively, such that participants responded 73 ± 25 ms faster when object preview was presented than when it was absent. The main effect of response was also significant for both RTs and errors, \( F(1, 20) = 16.72, p = .001, \text{MSE} = 8040.78, \eta^2 = .46 \) and \( F(1, 20) = 4.96, p = .038, \text{MSE} = .001, \eta^2 = .20 \), respectively, indicating that “same” responses were 28 ± 14 ms faster and 0.7 ± 0.6% less accurate than “different” responses. There was a significant interaction between preview and object for RTs but not errors, \( F(1, 20) = 13.53, p = .001, \text{MSE} = 1933.14, \eta^2 = .40 \) and \( F< 1, p< .1 \), respectively. When object preview was absent, there was a 16 ± 9 ms between-object superiority (\( F(1, 20) = 14.82 \)). When object preview was present, between-object superiority (8 ± 11 ms \( F(1, 20) = 2.62 \)) was eliminated. The preview x object interaction is an important finding.

There was a significant interaction between object and response for RTs but not errors, \( F(1, 20) = 5.56, p = .029, \text{MSE} = 1719.47, \eta^2 = .22 \) and \( F(1, 20) = 2.66, p = .119, \text{MSE} = .002, \eta^2 = .12 \), respectively, such that between-object superiority (11 ± 9 ms) was obtained for same responses (\( F = 7.77 \)) but not different responses (-3 ± 11 ms, \( F < 1 \)). This replicates the results of prior experiments in the present research. The interaction between depth and response was significant for RTs but not errors, \( F(1, 20) = 6.69, p = .018, \text{MSE} = 1274.16, \eta^2 = .25 \) and \( F < 2.50 \), respectively. For same responses, participants responded 12 ± 9 ms faster when only one object was occluded than when
both objects were unoccluded and occluded ($F = 6.86$). For different responses, there was no difference between the two depth levels ($F < 1$). Whether or not depth level influences same vs. different responses is not of central interest. Hence, this interaction will not be further discussed. The main effect of depth ($F(1.20) = 1.58$, $p = .22$) and the interactions between depth and other variables ($Fs < 2.06$) were not significant. Tables 5 and 6 show mean reaction times and errors as a function of preview and object and a function of object and response, respectively.

Experiment 5 included object preview as a within-subjects variable. Between-object superiority was obtained when object preview was absent but not when object preview was present. With the pre-exposure of the object, no statistically significant within-object superiority was observed. Davis et al. (2005) pointed out that within-object superiority should be obtained in the condition where there is object preview, which is not supported by the results of the current experiment which used occluded objects. The effect of object preview on between-object superiority (i.e., object preview eliminates between-object superiority) was found in the current experiment, even when preview was manipulated as a within-subjects variable. Experiment 4 and 5 used object with occlusion, and the results of preview effect on between-object superiority were obtained in both experiments. However, previous research (e.g., Experiment 2 in Marino and Scholl, 2005) also employed object preview and found within-object superiority in the two-rectangle paradigm (two separate rectangles or parallel lines were used, instead of objects with occlusion). Davis and Holmes (2005) concluded that use of object preview is one of the four criteria necessary to obtain within-object superiority. The failure to observe within-object superiority in Experiments 4 and 5 when object preview was present might be due
to the objects with occlusion being used. Experiment 6 was designed to examine whether object preview has different effects on object-based selection when targets appeared in occluded and separate objects.

**Experiment 6**

**Methods**

*Participants.* Twenty three new undergraduates from the same population as in Experiment 1 participated for course credits. The data from three participants were excluded in the final analysis, because the accuracy rates were below 90%.

*Materials.* The same stimuli were employed in the current experiment as in Experiment 2. However, only both-no-occlusion and both-occlusion displays were included in the current experiment. In addition, another condition in which the display consisted of only 2 equidistant rectangles (see the left panel of Figure 13) was included.

*Procedure and Design.* The procedure was similar to that used in Experiment 5. Instead of blocking the presence and absence of object preview, the trials with presence or absence of object preview were randomly intermixed. Three types of display (both-no-occlusion, both-occlusion, and separate rectangles) were also randomly mixed within a block.

**Results and Discussion**

The data trimming procedures removed 4.5% of the trials. The data from all cells in Experiment 2 are presented in Appendix G.

A 2 (Preview: absence vs. presence) x 3 (Display type: both-no-occlusion, both-occlusion, and separate rectangles) x 2 (Object: within vs. between) x 2 (Response: “same” vs. “different”) repeated measures of ANOVA was conducted on mean reaction
times and errors, respectively. Only significant effects and effects of central interest are reported. There was a main effect of preview for RTs but not errors, $F(1, 19) = 181.04, p = .000, MSE = 4092.03, \eta^2 = .91$ and $F(1, 19) = 2.24, p = .151, MSE = .000, \eta^2 = .11$, respectively, indicating that participants responded $78 \pm 12$ ms faster when object preview was present than when preview was absent. The main effect of object was significant for both RTs and errors, $F(1, 19) = 4.64, p = .044, MSE = 536.44, \eta^2 = .20$ and $F(1, 19) = 12.03, p = .003, MSE = .000, \eta^2 = .39$, respectively, such that there was a $14 \pm 13$ ms ($0.6 \pm 0.4\%$) overall between-object superiority. The main effect of response was also significant for both RTs and errors but in opposite directions, $F(1, 19) = 22.05, p = .000, MSE = 6790.84, \eta^2 = .54$ and $F(1, 19) = 28.79, p = .000, MSE = .001, \eta^2 = .60$, respectively, indicating that “same” responses were $35 \pm 16$ ms faster and $1.3 \pm 0.5\%$ less accurate than “different” responses. There was a significant interaction between preview and object for RTs but not errors, $F(1, 19) = 4.63, p = .045, MSE = 1574.43, \eta^2 = .19$ and $F(1, 19) = 1.21, p = .286, MSE = .001, \eta^2 = .06$, respectively. Table 7 gives mean reaction times and errors as a function of preview and object. Between-object superiority was obtained when object preview was absent ($20 \pm 14$ ms, $F(1, 19) = 8.58; 0.9 \pm 0.7\%$, $F(1, 19) = 7.73$) but not when object preview was present ($9 \pm 16$ ms, $F(1, 19) = 1.25; 0.4 \pm 0.6\%, F (1, 19) = 2.31$). Mean reaction times and errors are shown in Table 8 as a function of object and response. The interaction between object and response was significant for both RTs and errors, $F(1, 19) = 4.46, p = .048, MSE = 1574.43, \eta^2 = .19$ and $F(1, 19) = 5.35, p = .032, MSE = .001, \eta^2 = .22$, respectively. For “same” responses, there was a $22 \pm 13$ ms or $1.3 \pm 0.9\%$ between-object superiority ($F(1, 19) = 12.19$ and $F$
(1, 19) = 9.70 for RTs and errors, respectively). For “different” responses, no statistically significant effect was obtained (7 ± 18 ms and 0 ± 0.5%, $F_s < 1$). This result replicates findings in prior experiments. Table 9 provides mean reaction times and errors as a function of preview, object, and response. The 3-way interaction between preview, object, and response was also significant for RTs but not errors, $F (1, 19) = 5.36, p = .032$, MSE = 1493.30, $\eta^2 = .22$ and $F (1, 19) = 1.50, p = .236$, MSE = .000, $\eta^2 = .07$, respectively. When object preview was absent, a 36 ± 12 ms (and 1.7 ± 1.3%) between-object superiority was obtained for “same” responses ($F (1, 19) = 42.13$ and $F (1, 19) = 8.06$ for RTs and errors, respectively) but not “different” responses (5 ± 23 ms and 0 ± 0.6%, $F_s < 1$). When object preview was present, no between-object superiority or statistically significant within-object superiority was found (8 ± 18 ms, $F < 1$ and 0.8 ± 1.0%, $F (1, 19) = 3.78$ for “same” responses; 9 ± 18 ms, $F = 1$ and 0 ± 0.6%, $F < 1$ for “different” responses). The main effect of display type was not significant ($F (1, 19) = 1.20, p = .309$), and the interactions between display type and other variables were not significant, either (all $F_s < 2.08$).

Experiment 6 examined the effect of object preview on attentional selection by including three types of displays: two unoccluded objects with occlusion, two occluded objects, and two rectangles. A between-object superiority was obtained only for same responses when object preview was absent. There was no within-object superiority found even when two separate rectangles were included. The difference between Experiment 6 and the previous study (e.g., Marino & Scholl, 2005) that obtained within-object superiority lies in the duration of object preview. That is, the current experiment used a short duration (200 ms) for object preview, whereas Marino and Scholl (2005) used a
long duration (1000 ms). Shomstein and Behrmann (2008) compared the two durations in 2 experiments and found within-object superiority only for long duration (1000 ms) of object preview, but not for short duration (200 ms). The results of Experiments 4-6 were consistent with the findings of no within-object superiority when object preview was of a short (200 ms) duration as in Shomstein and Behrmann (2008).

**General Discussion**

**Between-object superiority in objects with occlusion**

The current research was intended to replicate either within-object superiority or between-object superiority for occluded objects and to provide a theoretical explanation for the underlying mechanism of between-object superiority. The distinction between within-object superiority and between-object superiority has been discussed by Davis and Holmes (2005). They posed four criteria (the use of unfilled outline stimuli, use of overlapping stimuli, extensive pre-exposure of the objects, and number of intervening luminance edges) for obtaining within-object superiority. Some of these criteria have not been directly tested in previous research, such as the pre-exposure of objects, and overlapping stimuli. The occluded objects are perceptually more complicated than the separate objects in the two rectangle paradigm. Hence, the occluded object is considered to be a difficult condition of obtaining within-object superiority or between-object superiority. Therefore, the occurrence of a significant effect (either within-object or between-object) will provide strong evidence for object-based attention.

Behrmann et al. (1998) first observed within-object superiority for occluded objects, but others (e.g., Saiki, 2000) have failed to replicate their results. One reason for the failure of replication is that a few confounding factors (e.g., colinearity, symmetry,
probability, and depth level) were involved in the procedures and stimuli used by Behrmann et al. (1998). As discussed in the introduction, Behrmann et al. (1998, Experiment 1) equated the trial number for each of the three conditions: the within-object condition (targets on the single unoccluded object), occlusion condition (targets on the single occluded object), and different-object condition (targets on two objects). As a result, targets were presented within a same object at 2/3 of the time but on different objects at 1/3 of the time. Also, targets always appeared at the same depth level for the within-object conditions (within-object and occlusion), but at different levels for the between-object condition (two object condition). By including or removing the confounding factors in Behrmann et al.’s (1998) design, both Saiki’s (2000) and the present study showed that the within-object superiority found by Behrmann et al. (1998) can be attributed to these confounded variables. Saiki (2000) examined the effect of colinearity and symmetry. The current experiments were designed first to investigate the potential effects of probability of targets appearing in same vs. different objects and depth level and then to examine the effect of object preview in occlusion after controlling the above mentioned confounded factors.

Experiment 1 used stimuli and procedures similar to those in Behrmann et al. (1998) and manipulated the probability of targets that belong to same vs. different objects between subjects. Within-object superiority was obtained when the probability of targets appearing in same vs. different object confound was involved. But, between-object superiority was observed when the confound of probability of targets that appear in the same vs. different objects was removed. Between-object superiority in the objects with occlusion is a new finding which has not been obtained in previous research. Experiments
2-6 used a new set of displays with occlusion to control the confounding of the same or different depth level in within-object and different-object targets and to investigate the distinction between within- and between-object superiorities and the effects of object preview. Experiments 2 and 3 controlled all possible confounding variables (e.g., higher probability of targets appearing in the same object than in different objects and targets are on the same depth level when they appearing in the same object, but targets are on different depth levels when they belong to different objects in the occlusion displays). Between-object superiority was found for unoccluded and single-occluded objects for “same” responses but not different responses. (This dependence of between-object superiority on response has previously been obtained by Cepeda and Kramer, 1999)

Experiments 4-6 provided evidence for the effects of object preview on between-object superiority. Between-object superiority was replicated for unoccluded objects in same responses but not different responses. However, between-object superiority was only found when the object preview was absent. However, object preview did not produce statistically significant within-object superiority as predicted by Davis et al. (2005).

Both within-object superiority and between-object superiority have been found in the two-rectangle paradigm developed by Driver and Rafal (1994). A within-object superiority, but not a between-object superiority, was even found for occluded objects (see Behrmann et al., 1998). Several accounts [e.g., attention shifting (Lamy & Egeth, 2002), change of object representation (Watson & Kramer, 1999), and attentional prioritization (Shomstein & Behrmann, 2008)] have been proposed to explain the causes of within-object superiority, but none of them can be generalized to account for all the existing data. Between-object superiority in objects with occlusion obtained in the current
experiments is a new finding which cannot be explained by either shift of attention, object representation changes, or attentional prioritization, because no precues were used in the present experiments so that no shift or prioritization of attention occurs.

**Whole-object Matching: A New Account for Between-object Superiority**

Li and Neill (2009) proposed an account of whole-object matching to explain between-object superiority. That is, between-object superiority is caused by the process of whole-object matching, especially when targets are parts of the objects. Visual attention is directed to the two objects simultaneously. In the different-object (between-object) condition with targets presented at the ends of two objects, the task is easily performed by matching the two objects whereas in the same-object (within-object) condition with two targets presented at the ends of the same object, matching two objects does not help to do the task because the two objects are always different. Attention has to be redirected to the one object that has the targets. Redirection of attention from two objects to one target object may require extra time, which results in slower responses in the within-object condition relative to the between-object condition. Li and Neill (2009) reported a study to examine a prediction of whole-object matching. Two types of objects were included in 3 separate blocks: the rectangle block, the U-shape block, and the mixed block. (See Figure 13 for examples.) The rectangle block only consists of trials with two rectangles, the U-shape block only involves trials with two U-shapes, and the mixed block has trials with a rectangle and a U-shape. Participants were asked to perform the same/different matching task in all three blocks with block presentation order counterbalanced between subjects. Between-object superiority was found for both the rectangle block and the U-shape block. The magnitude of between-object superiority for
each type of the objects was statistically equal. However, between-object superiority was reversed to within-object superiority in the mixed block, although it was not significant.

The whole-object matching account predicts that between-object superiority should be decreased in conditions that make object matching more difficult, or that between-object superiority should be eliminated when no object matching is possible. In objects with occlusion, the occluded object is represented as a whole object once the amodal completion process is finished. Therefore, whole-object matching could occur in the condition for objects with occlusion. Even though occluded objects are perceptually more complicated (two objects overlap with one another and some part of one object is not visible), the whole-object matching account still predicts between-object superiority for occluded objects as long as the two properties to be judged are perceived as parts of the whole object. Given that occlusion may make the object matching more difficult than in the case of separate objects, between-object superiority for the occlusion objects might be smaller as compared with the separate objects.

Between-object superiority was found in the current experiments when there is no probability of targets appearing in same vs. different objects confounding or object preview. Why was between-object superiority eliminated by probability of targets that belong to same vs. different objects and object preview? According to the whole-object matching theory, the occurrence of whole-object matching requires attention to be distributed on the two objects that may contain the targets. With the probability confounding of targets appearing on the same object more often than on different objects, attention may be biased to only one but not two objects which reduces the occurrence of the object matching. Hence, no between-object superiority was found. Following the
same logic, when object preview is present, the presentation of targets may serve as pop out events that attract attention to the targets per se so that the whole objects are not within the attention focus. Therefore, no whole-object matching will occur for the target display and no between-object superiority is observed.

Note that between-object superiority was only obtained for “same” responses but not “different” responses. The interaction between object and response was also found in previous research, Cepeda and Kramer (1999, Experiment 1) found a greater between-object superiority for “same” responses than for “different” responses. According to the whole-object matching theory, participants perform the match (“same” responses) /mismatch (“different” responses) task by comparing the whole objects. The targets (triangle-shaped notches or square-shaped notches) are perceived as parts of the objects. Whole object matching is helpful to the match/mismatch task in the between-object condition when two targets are on two different objects, because it is easier to match whole objects than to match two targets within the same object, which requires perceptually isolating the two smaller targets within the object from the initially perceived whole-object representation. However, in the within-object condition when two targets are on the same object, whole object matching biases mismatch (“different”) responses, because the two objects are always different (i.e., one with two targets and the other without targets). Participants must therefore spend extra time to resolve the conflict between the “different” response activated by the mismatch at the whole object level and the “same” response activated by the matching targets. The difference in “same” responses between the within-object and between-object conditions therefore is greater than the difference in “different” responses between the same-object vs. different-object
conditions.

Also, across the current six experiments, “same” responses were always faster and less accurate than “different” responses. This speed-accuracy tradeoff is typically found in perceptual matching tasks and has been labeled the “fast-same effect”. The noisy-operator theory of Krueger (1978) assumes that internal noise has major influence on match/mismatch task. This theory proposes that internal noise is more likely to produce featural mismatches than matches and that rechecking is needed when performing mismatch task which yields longer RTs and fewer errors for “different” responses.

Another important finding of the current experiment is that object preview eliminates between-object superiority but does not produce within-object superiority. Why is between-object superiority eliminated by the presence of object preview? There are two possible explanations. One is that object preview eliminates the occurrence of whole-object matching. That is, when object preview is present, the representation of objects may be completed during the preview. Two targets following the object preview are then perceived as separate from (not parts of) the already established whole object representations. Hence, no whole object matching occurs when the targets are presented. The other, similar explanation is that object preview results in the popout onset of the two targets such that attention is then attracted to the specific target locations, but not to the whole objects. If the onset transient of targets attracts attention, then removing the popout effect would restore between-object superiority. However, the prediction of target onset effect on object-based attention is not supported by the results of another experiment conducted in our lab. In that experiment, a 100 ms gap (blank screen) was inserted between object preview and the target display. Because the whole objects and targets now
have simultaneous onsets, the appearance of the targets should no longer draw attention
to their locations and away from the whole object representations. Thus, the gap should
not eliminate the between-object superiority effect. However, if the whole object
representations established by the preview persist across the short gap, as seems highly
likely, the later appearance of the targets would still be perceived as the targets being
separate from the already established whole-object representations such that the gap
should not eliminate between-object superiority. Thus, the absence of a between-object
superiority in the preview condition whether or not the gap was present or absent is
against the attentional capture by target onset account and supports that the later
appearance of the targets caused them to be perceived as objects separate from the whole
object representations that were established by the preview.

Whole-object Matching vs. Mental Rotation

Cepeda and Kramer (1999) reported two experiments that produced both
between- and within-object superiority. Based on participants’ subjective reports after
performing the experiments, Cepeda et al. (1999) proposed that mental translation or
rotation was responsible for attentional selection. Within-object superiority was found
when participants used a strategy of mental rotation, but between-object superiority was
produced when only mental translation was used but no mental rotation. The distinction
between within-object superiority and between-object superiority was only obtained for
same responses. According to Cepeda et al. (1999), within-object superiority should be
observed for the stimuli used in Behrmann et al. (1998) and the current experiments that
used the same stimuli. However, between-object superiority was found in the current
experiments when removing the confound of probability of targets appearing in same vs.
different objects. Even if there is mental rotation required (the objects were tilted in Behrmann et al.’s stimuli), between-object superiority, instead of within-object superiority, was obtained. Hence, it seems that between-object superiority is caused by the occurrence of the whole-object matching, not mental rotation.

**Comments on Davis and Holmes’ (2005) Criteria for Obtaining Within-object Superiority**

Unfilled outlines and occluded objects were used in the present Experiments 1, and filled and occluded objects were used in Experiments 2-6. Between-object superiority was produced by for both unfilled outline and filled objects, which is opposite to Davis et al.’s (2005) conclusion that within-object superiority should be obtained when outlined objects are used. In addition, object preview is another of Davis and Holmes’ (2005) criterion for within-object superiority. In Experiments 4-6, which examined the effect of object preview, between-object superiority was found in the absence of object preview but no statistically significant within-object superiority was found when object preview was present. Another criterion is the number of intervening luminance edges, which was not examined in the present experiments. Davis et al. (2005) proposed that within-object superiority should be observed when there is an unequal number of intervening edges between two targets but between-object superiority should be obtained when there is an equal number of intervening edges (see stimuli in Figure 5). However, Behrmann et al. (1998) found within-object superiority in stimuli with equal numbers of intervening edges in the within- and between-object conditions. Saiki (2000) also found within-object superiority for “same” responses and between-object superiority for “different” responses in the stimuli with equal numbers of intervening edges. The last factor that is responsible
for within-object superiority is the use of overlapping stimuli. Some unpublished experiments in our lab directly compared notches (targets do not overlap with the whole object representations but rather are a part of them) and wedges (targets are perceived as separate objects that overlap with the whole object representations). Between-object superiority was obtained for notches, but no statistically significant effect was obtained for wedges. Therefore, although the use of outline stimuli, use of overlapping stimuli, extensive pre-exposure of objects, and number of intervening luminance edges are some common aspects in research that has found within-object superiority, they are neither necessary nor sufficient conditions for obtaining within-object superiority. However, Davis et al. (2005) did not make it clear whether each of these four separate criteria is sufficient to produce within-object superiority or whether some of them must be combined together to produce within-object superiority.

**Necessary Conditions for Between-object Superiority vs. Within-object Superiority**

Between-object superiority and within-object superiority are two contrasting effects found in research on object-based attentional selection. In addition, these two effects have been obtained in the same paradigm using similar stimuli. Thus an important issue is in which condition(s) between-object superiority vs. within-object superiority will be obtained. Davis and Holmes (2005) made efforts to answer this question, but they failed to come up with the correct answer. Based on the results of the current experiments and previous research (e.g., Cepeda & Kramer, 1999; Davis & Holmes, 2005), between-object superiority should be obtained when target features are perceived as parts of the whole object representations but only if the task is a match/mismatch task. Although between-object superiority was found by Huang (2010, Experiment 8) in a counting task
(i.e., the task was to count whether one or two targets were present) that did not require perceptual matching of the targets, we failed to replicate this effect in our lab using the counting task. Thus, it seems that between-object superiority is not a robust result in tasks other than perceptual matching tasks. Within-object superiority should be obtained when attention is directed to only one object instead of two objects. This occurs when targets are presented more often in the same object than in different objects in both the pre-cuing paradigm and the divided attention paradigm.

**Between-object Superiority and Object-based Attention**

Object-based attention assumes that attention selects only one object at a time and that the properties within a same object are processed more efficiently than the properties belonged to different objects. Within-object superiority provides support for object-based attention. Between-object superiority is an effect opposite to within-object superiority. However, between-object superiority does not contradict object-based attention. The whole-object matching account of between-object superiority assumes that attention can be distributed to more than one object at a time but the unit of attentional selection is still the object. Davis et al. (e.g., Davis, 2001; Davis, Driver, Pavani, & Shepherd, 2000; Davis, Welch, Holmes, & Shepherd, 2001) have also argued that within- and between-object superiorities were both evidence for object-based attention. In addition, the result of up to 4 targets tracked correctly in a multiple object tracking task (participants visually track 2 or 4 targets moving with 8-10 objects and report whether a target or a distractor is cued) provided evidence that more than one object can be attended at a time (Pylyshyn, 1989; 1994).

The current experiments are the first to find between-object superiority in objects
with occlusion with the confounded effects of probability (with higher probability of targets appearing in the same object than in different objects) and depth level (targets presented on the same depth level in the same-object condition and on different depth levels in the different-object condition) that occurred in previous studies. Additionally, the present experiments found that Davis et al.’s (2005) criteria for determining whether within- vs. between-object superiority will be obtained failed to correctly predict the finding(s) of between-object superiority for matching targets (“same” responses) but not for mismatching targets (“different” responses) in the present experiments. Based on the present results it seems that between-object superiority is best explained by the whole-object matching theory, which assumes object-based attention and says that attention can be distributed on two objects containing targets and the two targets are compared via the whole-object matching. In conditions where the whole-object matching is difficult to occur, between-object based superiority is eliminated.
References


Davis, G., Driver, J., Pavani, F., & Shepherd, A. (2000). Reappraising the apparent costs
of attending to two separate visual objects. *Vision Research, 40*, 1323-1332.


Shomstein, S., & Yantis, S. (2002). Configural and contextual prioritization in object-
### Appendix A. Data for all cells in Experiment 1

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<td>BOS2</td>
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*Note.* BOS1 is the difference between the conditions of the same-object-nonocclusion and the different-object. BOS2 is the difference between the conditions of the same-object-occlusion and the different-object. Positive numbers represent between-object superiority.
Appendix B

*Data for all cells in Experiment 2*

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### Appendix C

*Data for all cells of the occlusion-encouraging block in Experiment 3*

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<td>(3.1 ± 2.5)</td>
<td>(-1.3 ± 1.5)</td>
<td>(1.8 ± 2.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>54 ± 47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2.6 ± 2.1)</td>
</tr>
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</table>
Appendix D

*Data for all cells in Experiment 3*

<table>
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<tr>
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<th>Discouraging-occlusion Block</th>
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</tr>
<tr>
<td></td>
<td>“Same”</td>
<td>“Different”</td>
</tr>
<tr>
<td></td>
<td>“Same”</td>
<td>“Different”</td>
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<td>Within-object</td>
<td>751(6.6)</td>
<td>784(1.9)</td>
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<tr>
<td></td>
<td>769(5.5)</td>
<td>769(1.0)</td>
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<tr>
<td>Between-object</td>
<td>686(3.4)</td>
<td>762(1.2)</td>
</tr>
<tr>
<td></td>
<td>699(1.9)</td>
<td>762(1.4)</td>
</tr>
<tr>
<td>BOS</td>
<td>65 ± 25</td>
<td>70 ± 24</td>
</tr>
<tr>
<td></td>
<td>(3.2 ± 3.6)</td>
<td>(3.6 ± 4.1)</td>
</tr>
<tr>
<td></td>
<td>22 ± 38</td>
<td>7 ± 35</td>
</tr>
<tr>
<td></td>
<td>(0.7 ± 1.7)</td>
<td>(-0.4 ± 1.2)</td>
</tr>
<tr>
<td></td>
<td>64 ± 28</td>
<td>-4 ± 24</td>
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<tr>
<td></td>
<td>(1.8 ± 2.9)</td>
<td>(0.5 ± 2.1)</td>
</tr>
<tr>
<td></td>
<td>60 ± 28</td>
<td>54 ± 46</td>
</tr>
<tr>
<td></td>
<td>(2.6 ± 2.1)</td>
<td>(-0.5 ± 1.4)</td>
</tr>
</tbody>
</table>
Appendix E

Data for all cells in Experiment 4

<table>
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<th>Same Depth</th>
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<th>Different Depth</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No Occlusion</td>
<td>Occlusion</td>
<td>No Occlusion</td>
<td>Occlusion</td>
</tr>
<tr>
<td></td>
<td>&quot;Same&quot;</td>
<td>&quot;Different&quot;</td>
<td>&quot;Same&quot;</td>
<td>&quot;Different&quot;</td>
</tr>
<tr>
<td>Within-object</td>
<td>619(2.9)</td>
<td>648(1.5)</td>
<td>637(3.5)</td>
<td>645(1.8)</td>
</tr>
<tr>
<td>Between-object</td>
<td>620(3.2)</td>
<td>650(1.4)</td>
<td>605(3.6)</td>
<td>649(2.2)</td>
</tr>
<tr>
<td>BOS</td>
<td>-1 ± 23</td>
<td>-2 ± 38</td>
<td>32 ± 18</td>
<td>-4 ± 34</td>
</tr>
<tr>
<td></td>
<td>(-0.3 ± 1.7)</td>
<td>(0.1 ± 1.1)</td>
<td>(-0.1 ± 2.0)</td>
<td>(-0.4 ± 1.5)</td>
</tr>
</tbody>
</table>

|                     | No Occlusion     | Occlusion           | No Occlusion      | Occlusion         |
|                     | "Same"           | "Different"         | "Same"            | "Different"      |
|                     | 613(3.3)         | 643(1.9)            | 625(4.0)          | 638(1.8)         |
|                     | 624(3.3)         | 654(1.7)            | 622(2.3)          | 645(2.3)         |
| BOS                 | -9 ± 22          | -11 ± 23            | 3 ± 20            | -7 ± 26          |
|                     | (0.0 ± 1.8)      | (0.2 ± 1.8)         | (1.7 ± 1.6)       | (-0.5 ± 1.7)     |
Appendix F

*Data for all cells in Experiment 5*

<table>
<thead>
<tr>
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<th>Same Depth</th>
<th>Different Depth</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>No Occlusion</td>
<td>Occlusion</td>
</tr>
<tr>
<td><strong>“Same”</strong></td>
<td><strong>“Different”</strong></td>
<td><strong>“Same”</strong></td>
</tr>
<tr>
<td><strong>Object Preview Absence</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-object</td>
<td>699(3.8)</td>
<td>736(1.5)</td>
</tr>
<tr>
<td>Between-object</td>
<td>680(1.2)</td>
<td>720(2.9)</td>
</tr>
<tr>
<td>BOS</td>
<td>19 ± 18</td>
<td>16 ± 31</td>
</tr>
<tr>
<td></td>
<td>(2.6 ± 1.7)</td>
<td>(-1.4 ± 2.1)</td>
</tr>
<tr>
<td><strong>Object Preview Presence</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-object</td>
<td>619(1.8)</td>
<td>628(1.8)</td>
</tr>
<tr>
<td>Between-object</td>
<td>628(1.8)</td>
<td>645(1.5)</td>
</tr>
<tr>
<td>BOS</td>
<td>-9 ± 25</td>
<td>-17 ± 23</td>
</tr>
<tr>
<td></td>
<td>(0.0 ± 2.1)</td>
<td>(0.3 ± 1.8)</td>
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Appendix G

Data for all cells in Experiment 6

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<th>Both-no-occlusion</th>
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<td>“Same”</td>
<td>“Different”</td>
<td>“Same”</td>
</tr>
<tr>
<td>Object Preview Absence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-object</td>
<td>696(4.0)</td>
<td>715(1.8)</td>
<td>715(3.9)</td>
</tr>
<tr>
<td>Between-object</td>
<td>653(2.6)</td>
<td>721(1.5)</td>
<td>683(1.8)</td>
</tr>
<tr>
<td>BOS</td>
<td>43 ± 22</td>
<td>-6 ± 34</td>
<td>32± 28</td>
</tr>
<tr>
<td></td>
<td>(1.4 ± 2.5)</td>
<td>(0.3 ± 1.1)</td>
<td>(2.1 ± 1.8)</td>
</tr>
<tr>
<td>Object Preview Presence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-object</td>
<td>601(3.8)</td>
<td>634(1.7)</td>
<td>625(2.4)</td>
</tr>
<tr>
<td>Between-object</td>
<td>590(2.4)</td>
<td>622(1.8)</td>
<td>632(2.0)</td>
</tr>
<tr>
<td>BOS</td>
<td>11 ± 18</td>
<td>12± 21</td>
<td>-7 ± 37</td>
</tr>
<tr>
<td></td>
<td>(1.4 ± 1.7)</td>
<td>(-0.1 ± 1.2)</td>
<td>(0.4 ± 1.5)</td>
</tr>
</tbody>
</table>
Table 1

*Mean reaction times and error rates (%) for Experiment 1*

<table>
<thead>
<tr>
<th></th>
<th>Same response</th>
<th>Diff. response</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No Confound</td>
<td>Confound</td>
</tr>
<tr>
<td>Same-object-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nonocclusion</td>
<td>683 (4.1)</td>
<td>690 (3.8)</td>
</tr>
<tr>
<td>Same-object-</td>
<td>694 (4.7)</td>
<td>708 (4.1)</td>
</tr>
<tr>
<td>occlusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different-object</td>
<td>672 (3.3)</td>
<td>690 (3.2)</td>
</tr>
<tr>
<td>BOS(^1)</td>
<td>11±9*</td>
<td>0±10</td>
</tr>
<tr>
<td>(0.8±1.0)</td>
<td>(0.6±1.1)</td>
<td>(1.4±0.8)*</td>
</tr>
<tr>
<td>BOS(^2)</td>
<td>22±16*</td>
<td>18±11*</td>
</tr>
<tr>
<td>(1.4±0.9)*</td>
<td>(0.9±1.0)</td>
<td>(0.8±1.0)</td>
</tr>
</tbody>
</table>

*Note. * indicates a significant effect (*p* < .05). BOS = between-object superiority. BOS\(^1\) is the difference between the same-object-nonocclusion condition and the different-object condition. BOS\(^2\) is the difference between the same-object-occlusion condition and the different-object condition. Positive numbers indicate between-object superiority, and negative numbers indicate within-object superiority.*
Table 2

*Mean reaction times and error rates (%) as a function of Response and Object in Experiment 2*

<table>
<thead>
<tr>
<th></th>
<th>Same responses</th>
<th>Different responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within-object</strong></td>
<td>765 (6.5)</td>
<td>792 (1.9)</td>
</tr>
<tr>
<td><strong>Between-object</strong></td>
<td>722 (2.3)</td>
<td>789 (2.6)</td>
</tr>
<tr>
<td><strong>BOS</strong></td>
<td><strong>43 ± 17</strong>*</td>
<td><strong>3 ± 14</strong></td>
</tr>
<tr>
<td></td>
<td>(4.2 ± 3.6)*</td>
<td>(-0.7 ± 0.7)*</td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect (*p* < .05). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
Table 3

*Mean reaction times and error rates (%) as a function of Response and Object in Experiment 3 for the block that encourages amodal completion*

<table>
<thead>
<tr>
<th></th>
<th>Same responses</th>
<th>Different responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-object</td>
<td>734 (5.2)</td>
<td>741 (2.2)</td>
</tr>
<tr>
<td>Between-object</td>
<td>678 (2.7)</td>
<td>735 (2.7)</td>
</tr>
<tr>
<td>BOS</td>
<td>56 ± 20*</td>
<td>6 ± 13</td>
</tr>
<tr>
<td></td>
<td>(2.5 ± 1.5)*</td>
<td>(- 0.5 ± 0.9)</td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect (p < .05). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
Table 4

*Mean reaction times and error rates (%) as a function of Response and Object in Experiment 3*

<table>
<thead>
<tr>
<th></th>
<th>Same responses</th>
<th>Different responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-object</td>
<td>750 (5.4)</td>
<td>758 (2.1)</td>
</tr>
<tr>
<td>Between-object</td>
<td>688 (2.6)</td>
<td>750 (2.0)</td>
</tr>
<tr>
<td>BOS</td>
<td>62 ± 19*</td>
<td>8 ± 20</td>
</tr>
<tr>
<td></td>
<td>(2.8 ± 3.8)</td>
<td>(0.1 ± 0.7)</td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect (*p* < .05). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
### Table 5

**Mean reaction times and error rates (%) as a function of Preview and Object in Experiment 5**

<table>
<thead>
<tr>
<th></th>
<th>Preview absence</th>
<th>Preview presence</th>
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</thead>
<tbody>
<tr>
<td><strong>Within-object</strong></td>
<td>713 (2.1)</td>
<td>627 (1.7)</td>
</tr>
<tr>
<td><strong>Between-object</strong></td>
<td>697 (1.7)</td>
<td>636 (1.3)</td>
</tr>
<tr>
<td><strong>BOS</strong></td>
<td><strong>16 ± 9</strong>*</td>
<td><strong>- 8 ± 11</strong></td>
</tr>
<tr>
<td></td>
<td><em>(0.4 ± 1.8)</em></td>
<td><em>(0.4 ± 0.9)</em></td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect (*p* < .05). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
Table 6

*Mean reaction times and error rates (%) as a function of Response and Object in Experiment 5*

<table>
<thead>
<tr>
<th></th>
<th>Same responses</th>
<th>Different responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-object</td>
<td>660 (2.5)</td>
<td>681 (1.6)</td>
</tr>
<tr>
<td>Between-object</td>
<td>649 (1.3)</td>
<td>684 (1.4)</td>
</tr>
<tr>
<td>BOS</td>
<td><strong>11 ± 9</strong></td>
<td>-3 ± 11</td>
</tr>
<tr>
<td></td>
<td>(1.2 ± 2.8)</td>
<td>(0.2 ± 1.0)</td>
</tr>
</tbody>
</table>

*Note. * indicates a significant effect ($p < .05$). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.*
Table 7

*Mean reaction times and error rates (%) as a function of Preview and Object in Experiment 6*

<table>
<thead>
<tr>
<th></th>
<th>Preview absence</th>
<th>Preview presence</th>
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</thead>
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<td>Within-object</td>
<td>715 (2.8)</td>
<td>631 (2.3)</td>
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<tr>
<td>Between-object</td>
<td>695 (1.9)</td>
<td>622 (1.9)</td>
</tr>
<tr>
<td>BOS</td>
<td>20 ± 14*</td>
<td>9 ± 16</td>
</tr>
<tr>
<td></td>
<td>(0.9 ± 0.7) *</td>
<td>(0.4 ± 0.6)</td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect ($p < .05$). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
Table 8

*Mean reaction times and error rates (%) as a function of Response and Object in Experiment 6*

<table>
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<tr>
<th></th>
<th>Same responses</th>
<th>Different responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-object</td>
<td>659 (3.5)</td>
<td>687 (1.6)</td>
</tr>
<tr>
<td>Between-object</td>
<td>637 (2.2)</td>
<td>680 (1.6)</td>
</tr>
<tr>
<td><strong>BOS</strong></td>
<td><strong>22 ± 13</strong>*</td>
<td><strong>7 ± 18</strong></td>
</tr>
<tr>
<td></td>
<td>*(1.3 ± 0.9) *</td>
<td>*(0.0 ± 0.5) *</td>
</tr>
</tbody>
</table>

*Note.* * indicates a significant effect (*p* < .05). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
Table 9

Mean reaction times and error rates (%) as a function of Preview, Response, and Object in Experiment 6

<table>
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<tr>
<th></th>
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<th>Preview present</th>
<th></th>
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<td>Same responses</td>
<td>Diff. responses</td>
<td>Same responses</td>
<td>Diff. responses</td>
</tr>
<tr>
<td>Within-object</td>
<td>703 (3.8)</td>
<td>728 (1.7)</td>
<td>616 (3.1)</td>
<td>646 (1.4)</td>
</tr>
<tr>
<td>Between-object</td>
<td>667 (2.1)</td>
<td>723 (1.7)</td>
<td>608 (2.3)</td>
<td>637 (1.4)</td>
</tr>
<tr>
<td>BOS</td>
<td>36 ± 12*</td>
<td>5 ± 23</td>
<td>8 ± 18</td>
<td>9 ± 18</td>
</tr>
<tr>
<td></td>
<td>(1.7 ± 1.3) *</td>
<td>(0.0 ± 0.6)</td>
<td>(0.8 ± 1.0)</td>
<td>(0.0 ± 0.7)</td>
</tr>
</tbody>
</table>

Note. * indicates a significant effect ($p < .05$). BOS = between-object superiority, BOS is the difference between the within-object condition and the between-object condition.
FIGURE CAPTIONS

Figure 1. Examples of the Typical Sequence of Events (running left to right) Within Trials from the Major Conditions of Experiments 1 and 2 in Egly, Driver and Rafal (1994)

Figure 2. Stimuli and Sequence of Events in Experiments 1 of Lamy and Egeth, (2002)

Figure 3. Examples of Target Used in Experiment 2 of Marino and Scholl (2005)

Figure 4. Examples of Stimuli Presented in Experiment 1(A), Experiment 2 (C), and Experiment 3 (B) of Cepeda and Kramer (1999)

Figure 5. Example of Stimuli in Experiment 3 of Davis and Holmes (2005)

Figure 6. Examples of Stimuli Used in Behrmann, Zemel, and Mozer (1998)

Figure 7. Example of Three Types of Trials in Experiment 2 of Shomstein and Yantis (2004)

Figure 8. Examples of Stimuli in Experiments 1 and 2

Figure 9. Examples of Stimuli and Four Conditions in Atchley and Kramer (2001)

Figure 10. Examples of Objects Used in Experiments 2-6 in the Current Research

Figure 11. Examples of Stimuli Used in Experiment 3

Figure 12. An Example of Within-object Trial with Targets on the Occluded Object in Experiment 4

Figure 13. Examples of Objects Used in Li and Neill (2009)
Figure 1. Examples of the typical sequence of events (running left to right) within trials from the major conditions of Experiments 1 and 2 in Egly, Driver and Rafal (1994). The target appeared at the cued location on 75% of the trials, in invalid-same object on 12.5% of the trials, and in invalid-different object on 12.5% of the trials.
**Figure 2.** Stimuli and sequence of events in Experiments 1 of Lamy and Egeth, (2002).
Figure 3. Examples of target used in Experiment 2 of Marino and Scholl (2005). Each object contains either one or two brightened line segments as targets. The task was to determine whether the longer line(s) or the rectangle(s) had the same or different number of brightened segments (targets) at its (their) ends.
Figure 4. Examples of stimuli presented in Experiment 1(A), Experiment 2 (C), and Experiment 3 (B) of Cepeda and Kramer (1999). In A and B, the left panel represents a mismatch response on different-object trials, and the right panel represents a match response on same-object trials. In C, the left panel represents different-object aligned trials (match response), the middle panel represents different-object reversed trials (mismatch response), and the right panel represents same-object trials (match response).
Figure 5. Example of stimuli in Experiment 3 of Davis and Holmes (2005). The left penal represents same-object match trials in horizontal displays and the right penal represents different-object mismatch trials in vertical displays.
Figure 6. Examples of stimuli used in Behrmann, Zemel, and Mozer (1998).

- **A. X-shape Displays**
  - Same
  - Different

- **B. V-shape Displays**
  - Same
  - Different

- **a. Within-object**

- **b. Different-object**

- **c. Occlusion**
Figure 7. Example of three types of trials in Experiment 2 of Shomstein and Yantis (2004). The task was to respond whether a T or L was present in the target display.
Figure 8. Examples of stimuli in Experiments 1 and 2. The left panel represents the same-object-nonocclusion condition, the middle panel represents the same-object-occlusion condition, and the right panel represents the different-object condition.
Figure 9. Examples of stimuli and four conditions in Atchley and Kramer (2001). The black dots indicate the possible target locations.
Figure 10. Examples of objects used in Experiments 2-6 in the current research. There are four types of display: (A) the both-no-occlusion condition, (B) the both-occlusion condition, (C) the single-no-occlusion condition, and (D) the single-occlusion condition. This is an illustration for horizontal and vertical displays.
Figure 11. Examples of stimuli used in Experiment 3. The left and the middle panels represent the same-object conditions: two targets are on the “same” object (the large bar in the left panel and two small bars in the middle panel). The right panels represent the different-object condition.
Figure 12. An example of within-object trial with targets on the occluded object in Experiment 4.
Figure 13. Examples of objects used in Li and Neill (2009). The left panel represents the two-rectangle condition, the middle represents the two-U-shape condition, and the right panel represents the mixed condition.