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Strategic effects on object-based attentional selection

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Abstract

The same-object benefit, that is faster and/or more accurate performance when two target properties to be identified appear on one object than when each of the properties appear on different objects, has been a robust and theoretically important finding in the study of attentional selection. Indeed, the same-object benefit has been interpreted to suggest that attention can be used to select objects and perceptual groups rather than unparsed regions of visual space. In the present studies we report and explore a different-object benefit, that is faster identification performance when two target properties appear on different objects than when they appear on a single object. The results from the three experiments suggest that the different-object benefit was the result of mental rotation and translation strategies that subjects performed on objects in an effort to determine whether two target properties matched or mismatched. These image manipulation strategies appear to be performed with similar but not with dissimilar target properties. The results are discussed in terms of their implications for the study of object-based attentional selection.

PsycINFO classification: 2300; 2323; 2346

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1. Introduction

A number of spatial metaphors have been used to describe the manner in which attention is deployed in the visual environment. For example, Posner (1980); (see

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also Eriksen & Eriksen, 1974) suggested that visual attention operates like a spotlight with objects falling within its focus being preferentially processed. Other spatial metaphors such as a zoom lens and gradient have also been suggested as descriptors which better convey the flexibility with which attention can be deployed and reoriented in the visual field (Eriksen & St. James, 1986; Downing & Pinker, 1985; LaBerge & Brown, 1989). Indeed, these space-based models of visual attention have received a good deal of empirical support from both psychophysical and neuropsychological studies (Bashinski & Bacharach, 1980; Hahn & Kramer, 1998; Hillyard et al., 1996; Hoffman & Nelson, 1981; Kramer & Hahn, 1995; Posner, Walker, Friedrich & Rafal, 1984; Riddoch & Humphreys, 1983).

However, more recently it has become increasingly obvious that attention can also be used to select objects and perceptual groups rather than simply regions of visual space. One of the initial studies which supported this object-based conceptualization of visual selection was performed by Duncan (1984). In Duncan's studies subjects were presented with two overlapping objects, a box and a line, and were asked to identify two properties of the objects. The target properties, the orientation and texture of the line and the size and side of a gap in the box, could either be located on a single object (e.g. the orientation and texture of the line) or distributed between the two objects (e.g. the orientation of the line and size of the box). Despite the fact that the target properties were equidistant regardless of whether they were located on one or two objects, subjects were more accurate in their identification of the properties when they were located on a single object. This effect has subsequently been referred to as the same-object benefit. Such a pattern of results is inconsistent with space-based models since such models suggest that attention is focused independently of the objects or structure in the environment.

Additional research supportive of object-based attentional selection has been performed in focused attention (Baylis & Driver, 1992; Kramer & Jacobson, 1991), divided attention (Behrmann & Tipper, 1999; Duncan, 1993; Kramer, Wickens & Donchin, 1985; Kramer, Weber & Watson, 1997; Vecera & Farah, 1994; Watson & Kramer, 1999; Yantis, 1992) and cueing paradigms (Moore, Yantis & Vaughan, 1998; Tipper, Driver & Weaver, 1991). Furthermore, several neuropsychological studies have reported cases of neglect not only for the side of the visual field contralateral to a patient's lesion but also for a particular side of an object independent of the area of the visual field in which the object appeared (Behrmann & Moscovitch, 1994; Driver & Halligan, 1991; Tipper & Behrmann, 1996).

In an important series of studies Egly, Driver & Rafal (1994a), Egly, Rafal, Driver & Starrveveld (1994b) obtained evidence which suggests that both space-based and object-based attention can operate concurrently within the time course of a single experimental trial. Egly et al. presented subjects with two horizontally or vertically oriented rectangles, one on each side of a fixation cross. Subjects were required to respond if one of the ends of the two rectangles flashed. One of the rectangle ends was cued prior to the occurrence of the luminance increment target. The cue was predictive of the location of the subsequent target.

Egly et al. found that RTs were fastest when the luminance target occurred at the cued location, slower if the target appeared at the uncued end of the cued rectangle and slowest if the target appeared in the uncued rectangle. The difference in RT between the cued and uncued ends of the cued rectangle was interpreted in terms of the time required to re-orient a spatial beam of attention while the difference in RT between the uncued end of the cued rectangle and the uncued rectangle was interpreted in terms of the cost incurred when attention had to be shifted from one to the other rectangle. Thus, these data suggest that spatial and object-based modes of attention can operate cooperatively in the service of selective processing of information in the visual environment (see also Kramer & Jacobson, 1991; Lavie & Driver, 1996; Moore et al., 1998).

The original purpose of our current studies was to further investigate the interaction between space-based and object-based modes of attentional selection. To that end, we briefly presented subjects with stimuli like those illustrated in Fig. 1 (i.e. line drawings of two horizontally or vertically oriented wrenches). The subjects' task was to determine whether the two open-ends either matched (i.e. two rectangular open-ends or two rounded open-ends) or mismatched (i.e. one rectangular open-end and one rounded open-end). Prior to the presentation of the wrench pair one of the wrench ends was cued by a bar marker.

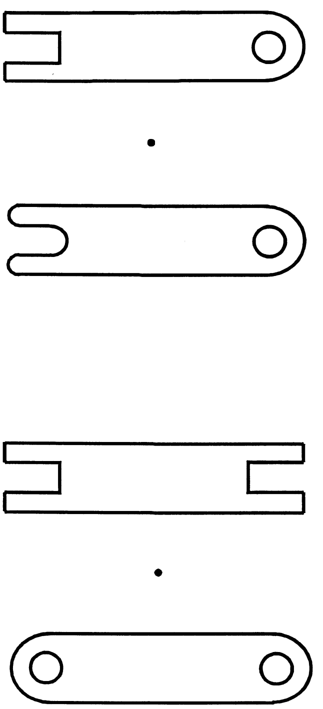

Fig. 1. A graphical illustration of the stimuli presented in Experiment 1. The top panel presents an illustration of a different-object trial (requiring a mismatch response). The bottom panel presents an illustration of a same-object trial (requiring a match response).

To our great surprise, results indicated a different-object performance benefit. That is, subjects were faster and more accurate when one target property (i.e. open wrench end) appeared on one wrench and the other target property appeared on the other wrench then when the two target properties appeared on a single wrench. Given that the wrench ends were both equidistant from fixation as well as equidistant from each other, whether they appeared on one or two wrenches, this pattern of results is consistent with neither space nor object-based models of attention. Thus, given the consistent same-object benefit that has been obtained in numerous previous studies when multiple target properties are to be identified (Baylis & Driver, 1993; Behrmann et al., in press; Duncan, 1984; Kramer et al., 1985, 1997; Vecera & Farah, 1994; Watson & Kramer, 1999; Weber, Kramer & Miller, 1997) our finding of a different-object benefit was an anomaly which required further investigation.

2. Experiment 1

The present experiment was conducted in an effort to replicate the different-object benefit that we obtained in our pilot study. In the pilot study, described above, subjects were presented with a spatially informative cue at the location at which one of the two target properties would subsequently appear. The two wrenches were then presented and subjects decided whether the two target properties, which appeared either on one wrench or distributed between two wrenches, were the same or different.

In the present study we decided to simplify the paradigm by presenting the two wrenches in the absence of the spatial cue. If the same pattern of results is obtained as in the pilot study, that is a different-object benefit, then we can be assured that whatever selection strategies the subjects are employing are not the result of any potential capture of attention engendered by the presentation of the spatially informative onset cue (Yantis, 1996).

2.1. Methods

2.1.1. Subjects

Seventeen students from the University of Illinois participated in the study and were paid $5.00 per hour for their time. The students ranged in age from 18 to 25 (mean age = 21.3). Fourteen of the students were female. All of the students had normal or corrected to normal acuity as measured by a Snellen chart.

2.1.2. Stimuli and apparatus

Stimuli were presented on an VGA monitor running in 640×480 mode. The refresh rate of the monitor was 72 Hz. The subjects used their left hand to depress the F key and their right hand to depress the J key on a standard QWERTY keyboard. Response timing was accurate to 1 ms.

The stimuli were drawn to resemble wrenches. Each display contained two wrenches centered on fixation (see Fig. 1). Each wrench was outlined in white (50.5

cd/m^2) and filled with gray (14.5 cd/m^2) and presented on a black background (0.02 cd/m^2). The subjects viewed the wrenches binocularly at a distance of 80 cm. A white fixation spot (0.36° visual angle) was present on the center of the display screen throughout the experiment. Three different types of wrench ends could be displayed; closed ends (non-targets), rounded open-ends (targets), and rectangular open-ends (targets). On a particular display there would always be two closed ends, with either both of these ends on a single wrench or one on one wrench and the other closed end on the other wrench, and either two rectangular or rounded open-ends or one of each type of wrench end. The rounded or rectangular open-ends could appear on either one wrench or one open-end could appear on one wrench and the other open-end on the other wrench.

Each of the two wrenches was 8.46° in length and 2.79° in width at a viewing distance of 80 cm. Wrench ends were 4.57° of visual angle from fixation and 4.43° of visual angle from the nearest wrench end. It is also important to note that wrench ends were equally spaced whether they appeared on one or two wrenches.

The subjects' task was to press one response button (either the F or J key) if the open-ends matched (i.e. two rounded open-ends or two rectangular open-ends appeared in the display) and another button if the open-ends mismatched (i.e. a rectangular open-end and a rounded open-end appeared in the display), regardless of whether the open-ends appeared on one or two wrenches. On 50% of the trials the two open-ends matched. Half of the match trials included two rounded open-ends the other half of the match trials included two rectangular open-ends. On the other 50% of the trials one rectangular and one rounded open-end appeared in the display.

On 50% of the trials the wrenches were presented horizontally aligned with one wrench above and one wrench below fixation. On the other 50% of the trials the wrenches were presented vertically with one wrench presented to the left and the other wrench presented to the right of fixation.

2.1.3. Procedure

Subjects began each trial by fixating on the center fixation dot. When they were ready they depressed the space bar and a pair of wrenches was presented for 56 ms. Once the subject made his or her response they could depress the space bar to begin the next trial.

Subjects performed 15 blocks of 64 trials each in a single experimental session. Feedback on accuracy and mean reaction time were provided at the end of each of the blocks. The first block was considered practice and was not analyzed. Participants were encouraged to take a rest break whenever they felt the need. Subjects were instructed to respond as quickly as possible and to maintain accuracy above 90%.

2.2. Results and discussion

The mean RT and accuracy data for the same and different object trials for the match and mismatch responses are presented in Table 1. These data were

Table 1
Mean RTs (ms) and accuracies for the same and different object trials for the match and mismatch responses in Experiment 1 (standard errors are in parentheses)

	Match response		Mismatch response	
	Same-object	Different-object	Same-object	Different-object
Mean RT	678 (14.9)	648 (13.1)	666 (15.8)	654 (17.2)
Accuracy	0.92 (0.008)	0.94 (0.007)	0.93 (0.008)	0.93 (0.009)

submitted to two-way repeated measures ANOVAs with object type (same and different) and response type (match and mismatch) as factors. A significant main effect was obtained for object type ($F(1,16) = 26.5$, $p < 0.01$) for RT. Subjects were faster on the different object than they were on the same-object trials (651 vs. 672 ms). A significant interaction was also obtained between object type and response type ($F(1,16) = 4.6$, $p < 0.05$). As can be seen in Table 1, the RT difference between same and different object trials was larger on the match than on the mismatch trials. However, post-hoc comparisons indicated that the different-object benefit for RT was significant for both the match and mismatch responses. [1] None of the main effects or interaction was significant for the accuracy measure.

These data replicate the pattern of effects obtained in our pilot study when the same stimulus displays were presented along with spatial cues. Therefore, the different object benefit cannot be attributed to the interaction of the spatial pre-cues with the imperative stimuli. How then can we account for such an effect, especially since the literature on object-based visual selective attention would suggest that responses should be faster when both of the target properties appear on the same object than when they appear on different objects (Baylis & Driver, 1993; Behrmann et al., in press; Duncan, 1984; Egly et al., 1994a; Kramer et al., 1985; Kramer & Watson, 1996; Lavie & Driver, 1996; Watson & Kramer, 1999)?

A clue to the reason for the discrepancy between the present results and the same-object benefit which has been repeatedly reported in the literature was provided by comments made by a number of our subjects concerning the manner in which they performed the task. Several subjects suggested that given the difficulty of distinguishing between the two target properties (i.e. the rounded and rectangular open-ends) they employed a strategy in which they attempted to overlap, in their mind's eye, the target properties. They claimed that they accomplished this by either translating one wrench to match the position of the other wrench (i.e. in the case of the different wrench trials on which one wrench could be moved laterally or vertically in order to superimpose it on the other wrench) or by rotating an image of a wrench so as to superimpose the target property on one end

[1] All post-hoc comparisons were performed with Bonferroni t-tests and were significant at $p < 0.05$.

with the target property on the other end of the same wrench (i.e. in the same-object trials).

Given what we know about the performance and processing costs required to perform a 180° mental rotation of an object (Forster, Gebhardt, Lindlar, Siemann & Delius, 1996; Pellizzer & Georgopoulos, 1993; Shepard & Metzler, 1971; Shepard & Cooper, 1982; Tagaris et al., 1997), the strategies articulated by the subjects provide a reasonable, albeit post-hoc, explanation of our finding of faster performance for the different-object than for the same-object trials. That is, the literature on mental rotation would clearly predict that it would take longer to rotate an object 180° than it would to translate an object a short distance either laterally or vertically.

3. Experiment 2

The main goal of Experiment 2 was to examine the strategic account of our results. To that end, it was important to ensure that we decoupled the two strategies, mental translation and rotation, reported by the subjects in Experiment 1 from the two object conditions. The way in which this was accomplished is illustrated in Fig. 2. As indicated in the figure we employed three different object conditions in the present study. Two of the object conditions, the same-object (bottom panel) and different-object aligned (top panel) configurations, were similar to those employed in Experiment 1 in that a rotation strategy would potentially apply to the same-object trials while a translation strategy would be applicable to the different-object aligned trials. The different-object reversed configuration, displayed in the middle panel of Fig. 2, is the key to decoupling the rotation/translation strategies from the object conditions. In this configuration, the two target properties, the open wrench ends, are oriented in opposite directions, as they are in the same-object configuration.

Thus, if the strategic account of the different-object benefit observed in Experiment 1 is correct we would expect the following effects in the present study. First, as was the case in Experiment 1 we would expect that subjects would be faster to respond on the different-object aligned trials (i.e. the top panel in Fig. 2) than on the same-object trials (i.e. the bottom panel in Fig. 2). Such an effect would be consistent with the time consuming nature of a mental rotation strategy that might be applied to align the target wrench ends on the same object trials. Second, given that both a rotation and a translation operation would be required on the different-object reversed trials (i.e. the center panel of Fig. 2), the strategic account would predict that performance should be slower with this configuration than on the same-object trials (on which only a rotation operation should be necessary). Thus, the strategic hypothesis predicts an ordering of the display configurations from fastest to slowest as follows – different-object aligned, same-object, and different object-reversed. As with Experiment 1, a straightforward object-based hypothesis predicts faster performance for the same-object than for either of the different object configurations while a space-based attention hypothesis predicts equivalent performance in each of the three configurations.

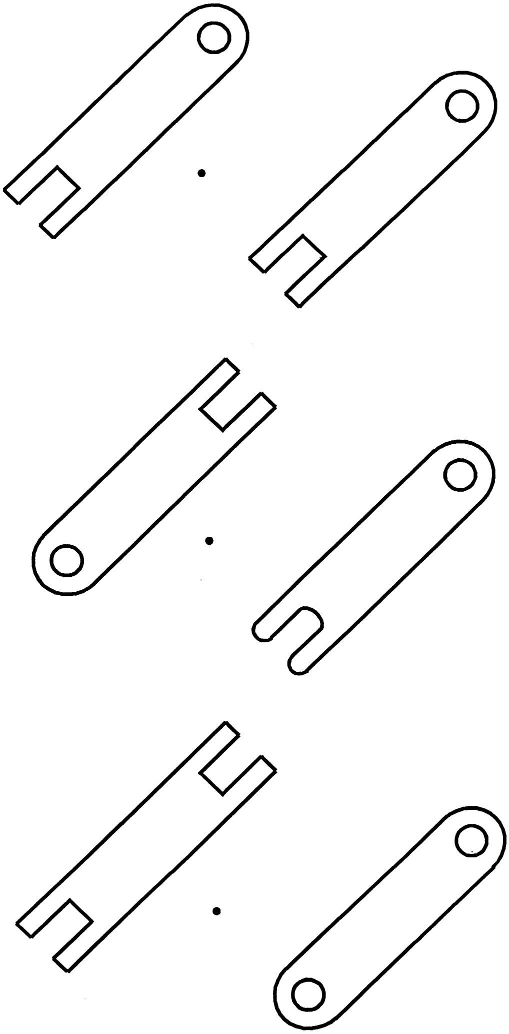

Fig. 2. A graphical illustration of the stimuli presented in Experiment 2. The top panel presents an illustration of a different-object aligned trial. The middle panel presents an illustration of a different-object reversed trial. The bottom panel presents an illustration of a same-object trial.

3.1. Methods

3.1.1. Subjects

Seventeen students from the University of Illinois participated in the study and were paid $5.00 per hour for their time. The students ranged in age from 18 to 27 (mean age = 22.7). Fourteen of the students were female. All of the students had normal or corrected to normal acuity as measured by a Snellen chart.

3.1.2. Stimuli and apparatus

The stimuli and apparatus in the present study were the same as those used in Experiment 1 with the following exceptions. First, rather than presenting the wrenches vertically or horizontally, the wrenches were tilted at a 45° angle with respect to vertical (see Fig. 2). Second, the wrenches were 6.91° in length and 1.7° in width. The two open-ends of the wrenches always appeared 3° in visual angle from fixation and 5.4° in visual angle from each other. One of the closed ends also appeared 3° from fixation and 5.4° from each of the open-ends. The other closed wrench end appeared 5.4° from fixation. Finally, as illustrated in Fig. 2 the wrenches were offset (i.e. one of the wrenches appeared higher in the display than the other wrench), so that retinal eccentricity and visual angle separation between open-ends could be maintained in the different-object aligned, different-object reversed, and same-object trials.

3.1.3. Procedure

The procedures were the same as those employed in Experiment 1.

3.2. Results and discussion

The mean RT and accuracy data for the same-object, different-object aligned and different-object reversed conditions for the match and mismatch response trials are presented in Table 2. These data were submitted to two-way repeated measures ANOVAs with object type (same-object, different-object aligned & different-object reversed) and response type (match and mismatch response) as within subjects factors. A significant main effect was obtained for object type for both RT ($F(1,16) = 38.2$, $p < 0.01$) and accuracy ($F(1,16) = 5.2$, $p < 0.01$). Consistent with the strategic hypothesis RTs were fastest for the different-object aligned configurations, slower for the same-object trials, and slowest for the different-object reversed trials (593, 608 and 622 ms, respectively). Post-hoc comparisons confirmed that each of these differences were significant. Accuracies for the different-object aligned, same-object and different-object reversed trials were 0.939, 0.930 and 0.915, respectively.

Table 2
Mean RTs (ms) and accuracies for the same object, different object aligned (Different *A*) and different object reversed (Different *R*) trials for the match and mismatch responses in Experiment 2 (standard errors are in parentheses)

	Match response			Mismatch response		
	Same	Different *A*	Different *R*	Same	Different *A*	Different *R*
Mean RT	611 (15.3)	587 (14.9)	640 (15.5)	604 (15.9)	598 (15.6)	605 (17.7)
Accuracy	0.93 (0.008)	0.94 (0.007)	0.90 (0.009)	0.93 (0.005)	0.94 (0.007)	0.93 (0.008)

The different-object aligned and same-object trials were significantly more accurate than the different-object reversed trials.

A significant interaction was also obtained between the object type and response type factors for RT ($F(1,16) = 12.7$, $p < 0.01$) and a marginally significant effect was obtained for accuracy ($F(1,16) = 2.8$, $p < 0.07$). As can be seen in Table 2, the RT pattern observed for the main effect of object type was obtained for the match but not for the mismatch response. RTs were fastest for the different-object aligned, slower for the same-object and slowest for the different-object reversed trials for the match response. These three conditions produced statistically equivalent RTs for the mismatch response. A similar pattern of results was obtained for accuracy.

In summary, the pattern of RTs and accuracies obtained on the match trials in the present study are consistent with the strategic hypothesis but not with either the object-based or space-based hypotheses. RTs were fastest when a translation operation was needed to superimpose two images of the wrenches (different-object aligned trials), slower when a rotation operation was necessary to superimpose the target wrench ends (same-object trials), and slowest when both a translation and rotation was required to superimpose images of the two wrenches (different-object reversed trials). The object-based hypothesis predicted faster responses when the two target properties appeared on a single object (wrench) than when one open-end appeared on one wrench and the other open-end appeared on the other wrench. Although the faster RTs obtained on the same-object than on the different-object reversed trials was consistent with the object-based hypothesis, the finding of slower RTs on the same-object than on the different-object aligned trials was not consistent with this hypothesis. The space-based hypothesis predicted equivalent RTs in the three objects conditions. Such a pattern of results was not obtained on the match trials. Thus, these data when viewed along with the results obtained in Experiment 1 provide strong support for our suggestion that subjects pursued a strategy in which they attempted to mentally superimpose images of the target properties to aid in deciding whether they were the same or different.

4. Experiment 3

The results obtained in Experiments 1 and 2 suggest that the adoption of strategies, such as mental rotation and translation (Shepard & Metzler, 1971; Shepard & Cooper, 1982; Taragaris et al., 1997), which can be used in the comparison of multiple stimuli can override or mask object-based attentional selection strategies (i.e. as inferred from a same-object performance benefit). However, an important unanswered question is why subjects in our studies appear to have adopted a translation/rotation strategy to enable the extraction of task-relevant information whereas evidence for the use of such strategies has not been obtained in other studies of object-based attentional selection?

One possibility concerns the nature of the subjects' task. We asked subjects to perform a same-different matching task, determining whether the target wrench ends were the same or different, while many previous studies of object-based attentional selection have employed either simple detection (Egly et al., 1994a,b), discrimination (Duncan, 1984; Moore et al., 1998; Vecera & Farah, 1994), focused attention (Baylis & Driver, 1992; Kramer & Jacobson, 1991; Yantis, 1992) or conjunction search tasks (Kramer & Watson, 1996; Watson & Kramer, 1999). Thus, it is conceivable that the same-different matching task encouraged subjects to utilize a strategy which enabled them to superimpose, in their mind's eye, the two potential targets for the purposes of deciding whether they were physically equivalent. The other tasks which have been used to investigate object-based selection would not necessarily benefit from such a strategy. However, this task-based hypothesis is inconsistent with the small but growing number of studies which have required subjects to perform a same-different matching task and have found evidence for object-based selection (Baylis & Driver, 1993; Lavie & Driver, 1996) even when the stimuli were arranged in a manner similar to that represented in Fig. 1 (Behrmann, Zemel & Mozer, 1998). Therefore, it would appear unlikely that the nature of the task would be responsible for subjects adopting a translation/rotation comparison strategy in the present studies.

However, it is conceivable that the nature of the task when viewed in conjunction with the difficulty of the discrimination required of the subject might encourage the use of a rotation/translation strategy. That is, previous investigations of object-based attentional selection that have used same-different matching tasks have required subjects to perform relatively easy discriminations between potential targets. For example, Lavie and Driver (1996) had subjects decide whether two dots, two gaps, or a dot and a gap were present on a set of lines. Behrmann et al. (1998) had subjects decide whether two or three divisions were present on the ends of two overlapping bars. In our task subjects were asked to make the relatively subtle distinction between a rounded and a rectangular wrench end that was presented for only 56 ms. Indeed, our subjects suggested that they adopted the translation/rotation strategy to aid them in making this difficult comparison. Interestingly, Forster et al., (1996) reported that subjects used a rotation strategy to compare non-mirror image polygons only when the discrimination among different polygons in a set was difficult.

In order to test the *perceptual difficulty hypothesis* [2] we changed the nature of the target stimuli that subjects were required to compare so as to make the distinction

[2] We conducted a control study in order to provide an objective performance-based basis for the perceptual difficulty hypothesis. Sixteen subjects participated in a study in which we briefly (56 ms) presented two wrenches and, in different blocks of trials, asked the subjects to determine whether one of the four target ends (i.e. the rectangular and rounded open-ends used in Experiments 1 and 2 and the bent-end and irregular open-end used in Experiment 3) was present on the display (the rest of the ends were closed-ends). The order of the four different target wrench-end blocks were counterbalanced across subjects. Subjects' performance was significantly faster ($F(3,45) = 10.2$, $p < 0.01$) and more accurate ($F(3,45) = 15,9$, $p < 0.01$) when they detected the wrench ends used in Experiment 3 than when the wrench ends used in Experiments 1 and 2 were the targets. The mean RTs for the rounded, rectangular, bent and irregular open-end wrench ends were 561, 569, 489 and 496 ms, respectively. The comparable accuracies for these four target conditions were 87.3, 87.8, 92.8 and 92.6 ms. Thus, these data are consistent with our hypothesis that the perceptual comparison difficulty was higher in Experiments 1 and 2 than it was in Experiment 3.

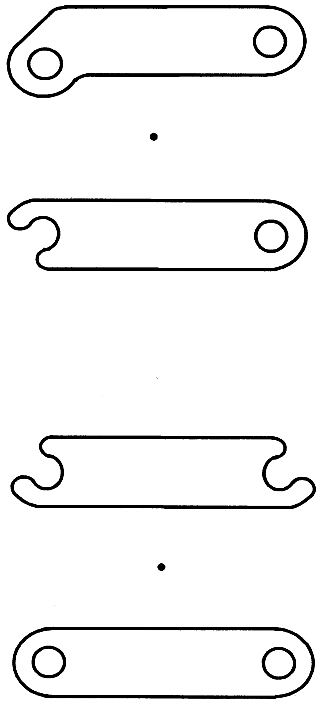

Fig. 3. A graphical illustration of the stimuli presented in Experiment 3. The top-panel presents a different-object trial requiring a mismatch response. The bottom panel presents an illustration of a same-object trial requiring a match response.

between targets more salient. As illustrated in Fig. 3, instead of having subjects make the subtle discrimination between rectangular and rounded wrench ends as in Experiments 1 and 2, we now asked subjects to decide whether two open-ends, two closed bent-ends, or one open-end and one bent-end were present on the briefly presented wrench pair. If the perceptual difficulty of the comparison was responsible for the subjects' use of the translation/rotation strategy in the first two studies we would now expect to find a same-object benefit in performance whenever the target appeared on a single wrench.

4.1. Methods

4.1.1. Subjects

Ten students from the University of Illinois participated in the study and were paid $5.00 per hour for their time. The students ranged in age from 20 to 31 (mean age = 22.0). Nine of the students were female. All of the students had normal or corrected to normal acuity as measured by a Snellen chart.

4.1.2. Stimuli and apparatus

The stimuli and apparatus were the same as those employed in Experiment 1 with the following exceptions. The wrench ends differed from those employed in Experiment 1. As illustrated in Fig. 3 the non-target wrench ends were closed and co-linear with the shaft of the wrench. The target wrench ends were the open-end and the bent closed-end. Two target wrench ends appeared in each display. The target wrench ends (which were the same or different) appeared on one wrench 50% of the trials and distributed between the two wrenches on the rest of the trials.

4.1.3. Procedure

The procedures were the identical to those employed in Experiment 1.

4.2. Results and discussion

The mean RT and accuracy data for the same and different object trials for the match and mismatch responses are presented in Table 3. These data were submitted to two-way repeated measures ANOVAs with object type (same and different) and response type (match and mismatch) as factors. Significant main effects for object type were obtained for both RT ($F(1,9) = 12.4$, $p < 0.01$) and accuracy measures ($F(1,9) = 21.2$, $p < 0.01$). Subjects were faster and more accurate to respond when the two target properties appeared on one object than when they were distributed between two different objects. None of the other main effects or interactions were significant. These data are consistent with the perceptual difficulty hypothesis. When we decreased the similarity of the target properties, as was the case with the open-end and bent-ends in the present study, subjects appeared to selectively attend to specific objects without the need to execute a translation/rotation strategy to successfully compare the wrench ends.

Table 3
Mean RTs (ms) and accuracies for the same and different object trials for the match and mismatch responses in Experiment 3 (standard errors are in parentheses)

	Match response		Mismatch response	
	Same-object	Different-object	Same-object	Different-object
Mean RT	610 (31.6)	637 (34.7)	611 (34.9)	631 (36.8)
Accuracy	0.97 (0.006)	0.94 (0.005)	0.96 (0.003)	0.93 (0.007)

5. General discussion

The results obtained in the present studies suggest that image manipulation strategies, such as mental rotation and translation, [3] are used by subjects when they are required to compare two similar target properties in order to decide whether they are physically the same or different. Indeed, the apparent use of such strategies resulted in the observation of a surprising result, a different-object performance benefit, in a paradigm which has previously produced robust performance effects (i.e. same-object benefits) that are consistent with object-based models of attentional selection (Baylis & Driver, 1993; Behrmann et al., 1998; Duncan, 1984; Vecera & Farah, 1994; Watson & Kramer, 1999; Weber et al., 1997).

In Experiment 1, we found that RTs were faster when the target properties appeared on two different line drawings of wrenches than when the target properties appeared on a single wrench. This pattern of results was replicated, for the match responses, for comparable stimuli in Experiment 2 (see the top and bottom panels of Fig. 2). Such a pattern of results is inconsistent with space-based models of attention (Eriksen & St. James, 1986; Posner, 1980) which predict no difference in the time required to compare the target properties when they appear on one or two wrenches. The results are also inconsistent with object-based models of attention (Baylis & Driver, 1993; Duncan, 1994; Watson & Kramer, 1999) which predict faster and/or more accurate performance when the target properties appear on a single object than when they appear on the two objects.

The explanation for the different-object performance benefit was provided by a comparison of the three object conditions in Experiment 2. Our explanation of the different-object benefit was based on the assumption that subjects were manipulating images of the wrenches in order to mentally superimpose the target properties in an effort to decide whether they match or mismatch. For example, the wrenches in the different-object aligned condition, represented by the wrench pair in the top panel of Fig. 2, could be superimposed by a translation operation. However, the superimposition of the target properties in the same-object conditions, represented in the bottom panel of Fig. 2, would require that a mental image of the wrench be rotated 180°. Thus, given the adoption of such image manipulation strategies the faster RTs

[3] One could argue that previous studies of the time course of mental rotation have suggested that a 180° rotation takes substantially longer than the RTs observed in the present studies (Forster et al.,1996; Pellizzer & Georgopoulos, 1993; Shepard & Metzler, 1971; Shepard & Cooper, 1982; Tagaris et al., 1997) and therefore a mental rotation strategy is unlikely to have been adopted. However, it is important to point out that the objects used in our studies were quite different than objects used in studies of mental rotation. For example, our objects had a clearly defined major axis of orientation and were relatively simple 2D line drawings of familiar objects while objects used in most mental rotation studies have tended to be unfamiliar and complex multi-angle stimuli with no major axis of orientation. Therefore, it is conceivable that mental rotation might be considerably faster with the objects which we employed than the kinds of objects which have been employed to study the mechanisms which underlie mental rotation. Of course, this issue should be systematically addressed in future research.

observed for the different-object conditions in Experiments 1 and 2 could be the result of the longer time required to perform a 180° rotation operation, in the same-object conditions, than the translation operation required to compare the two target properties on the different-object trials (Forster et al., 1996; Shepard & Metzler, 1971; Shepard & Cooper, 1982; Tagaris et al., 1997).

This image manipulation hypothesis was tested by adding an additional different-object condition in Experiment 2. In this different-object reversed condition, represented in the center panel of Fig. 2, the superimposition of the two target properties would require both a translation and a 180° rotation operation. Thus, if subjects were employing the hypothesized image manipulation strategies, RT should be longer in the different-object reversed condition than in either the same-object or the different-object aligned conditions. This was the pattern of results that we observed for the match responses.

In Experiment 3 we examined a potential explanation for why subjects in our studies employed translation/rotation image manipulation strategies to compare two target properties despite the fact that no evidence for the use of such strategies was obtained in other investigations of object-based attention in same/different matching tasks (Behrmann et al., 1998; Lavie & Driver, 1996). We hypothesized that image manipulation strategies might only be employed when physically similar target properties need to be compared (see Tagaris et al., 1997 for empirical support for this hypothesis with a Shepard & Metzler task) and therefore if we made the target properties more dissimilar subjects would select individual objects without the need to mentally superimpose them for the purposes of deciding whether they matched or mismatched. In order to examine this hypothesis we employed different target properties, illustrated in Fig. 3, that were physically dissimilar. The pattern of performance effects obtained in this study was consistent with our perceptual difficulty hypothesis. A same-object benefit, in RT and accuracy, was obtained with the physically dissimilar wrench ends.

The results of the three studies, when viewed together, suggest that while the presence of a same-object effect is diagnostic of object-based attentional selection (Baylis & Driver, 1993; Duncan, 1984; Tipper & Behrmann, 1996; Vecera & Farah, 1994; Kramer & Watson, 1996), its absence does not necessarily suggest that objects are not being selectively attended. Indeed, the image manipulation strategies that subjects appear to have employed in Experiments 1 and 2 are clearly object-based, in the sense that they involve the selective manipulation of particular objects in the display – rather than simply the selection of areas of space. However, as suggested by the findings obtained in Experiment 2, the use of such image manipulation strategies resulted in the opposite pattern of performance effects, a different-object benefit, than that observed in previous investigations of object-based attentional selection. A comparison of the results obtained in Experiments 1 and 2 and those obtained in Experiment 3 suggest that the use of image manipulation strategies for the comparison of multiple targets is based, at least in part, on the similarity of the targets to be compared. In summary, it would appear that it is important to consider the nature of the stimuli and tasks when examining the processes of attentional selection. Indeed, such considerations are likely to become more important as we transition the study of attention from well controlled, but often impoverished, laboratory displays and tasks to the study of attentional selection strategies in the real-world.

One additional finding merits some discussion. That is, while large and robust different-object benefits were obtained for the match responses in Experiments 1 and 2, the different-object benefits were either substantially smaller (Experiment 1) or non-significant (Experiment 2) for the mismatch responses. Why might this be the case? One possibility concerns the modes of selective attention that may be operating in our task. Egly et al., (1994a,b; see also Humphreys & Riddoch, 1993; Humphreys, Olson, Romani & Riddoch, 1996; Kramer & Jacobson, 1991) have argued that both object and space-based modes of attention may operate in a cooperative fashion within an experimental trial. Indeed, they have obtained empirical data in a cueing paradigm which is supportive of this speculation.

One could imagine that under conditions in which discriminations are expected to be difficult (i.e. Experiments 1 and 2) subjects might broadly deploy attention in the visual field at the beginning of a trial in an effort to extract the locations which are likely to contain the target properties. In some cases, particularly when there are different target properties presented in the display (i.e. target properties which should result in a mismatch response), the broadly distributed spatial attention might be sufficient to produce a response. However, in other cases, particularly when the target properties are identical, the mental superimposition of the target properties might be necessary to decide on the appropriate response. That is, both space and object-based selection strategies might operate in parallel to aid the subject in deciding whether similar target properties match or mismatch. Such an attentional strategy would likely produce much weaker evidence of object-based selection for mismatching targets than for matching targets, since mismatching targets would be compared via a mixture of space-based and object-based attentional modes while matching targets would be mainly compared via object-based strategies.

One way to further explore this hypothesis concerning the cooperative deployment of attentional strategies under conditions in which difficult comparisons are to be made would be to fit mixture distribution models to the RT distributions (Yantis, Meyer & Smith, 1991) in conditions like those in the present studies. Such a experimental strategy will require the collection of a substantial amount of data that can be used in the construction of mixture distributions of space-based and object-based attentional strategies as well as the construction of experimental conditions in which one or the other attentional strategy are used (i.e. in order to construct the basis distributions for the space and object-based strategies).

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