The Quarterly Journal of Experimental Psychology
Integrated in 2006

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100704

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First Published on: 05 May 2006
To link to this article: DOI: 10.1080/17470210600654792
URL: http://dx.doi.org/10.1080/17470210600654792

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2007, 60 (1), 137–153

Psychology Press
Taylor & Francis Group

Object-based attention is mediated by collinearity of targets

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Same-object bias occurs when tasks associated with processing a single object are faster than tasks associated with two objects. Over five experiments we assessed whether same-object bias is mediated by the collinearity of the targets. Participants decided whether two targets, presented either within a single object or across two objects, were the same or different. Results showed that same-object bias only occurred when targets appeared on the same straight line within the same object. When targets appeared in the same object but were separated by an angle or corner, within-object facilitation was eliminated or greatly reduced. In a final experiment, response times to two targets that were collinear but on separate objects were responded to faster than were noncollinear targets on the same object. This suggests that collinearity between targets mediates the effect found in this paradigm, at least to a greater extent than colour grouping.

Object-based attention is a popular conception of how visual attention is allocated to features in the visual world. It emerged in the early 1980s as a counter position to theories of spatial attention (B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & St. James, 1986; C. W. Eriksen & Yeh, 1985; Posner, 1980), and researchers argued that, logically and empirically, attention must be allocated to objects (e.g., Driver & Baylis, 1989; Kahneman & Henik, 1981; Lavie & Driver, 1996). Evidence in favour of object-based processing has been demonstrated in a wide variety of paradigms including experiments where responses associated with a single object gain a benefit compared to responses that require attention to move between objects (e.g., Baylis & Driver, 1993; Duncan, 1984; Vecera & Farah, 1994; Watson & Kramer, 1999), cueing experiments where the benefit of the cue moves with a cued object rather than remaining in the spatial location (Kahneman, Treisman, & Gibbs, 1992), and similarly, in studies where inhibition of return has moved with cued objects (Tipper, Driver, & Weaver, 1991). Furthermore, the selection priority of a new stimulus has also been shown to occur at the level of object representation

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http://www.psypress.com/qjep DOI:10.1080/17470210600654792

(Cole, Kentridge, & Heywood, 2004; Gellatly & Cole, 2000; Gellatly, Cole, & Blurton, 1999; Yantis & Hillstrom, 1994).

There are, however, several potential confounds that exist in object-parsing studies (Behrmann, Zemel, & Mozer, 1998; Brawn & Snowden, 2000; Saiki, 2000). For instance, it is remarkably difficult to define an object for the purposes of experimentation. Real-world objects may introduce many confounds in the interpretation of effects, while simplistic object representations may be accused of being impoverished stimuli. The majority of researchers have adopted the latter approach, tending to use simple geometric shapes, contours, or schematic objects. While such objects reduce the number of possible confounds that may be found with real-world objects, simplistic shapes may introduce problems of their own. One confound with the use of simple shapes was noted by Avrahami (1999) who explored the findings of Egly, Driver, and Rafal (1994).

Egly et al. (1994) presented participants with two large rectangles (either horizontally or vertically). One end of a rectangle was cued (i.e., illuminated) immediately before the presentation of a target. Valid targets appeared at the cued location. Invalid targets occurred either at the opposite end of the uncued rectangle (within object) or at the nearest end of the other rectangle (between object). Participants were faster on invalid within-object trials than on invalid between-object trials, despite both targets being the same distance from the cue in Euclidean space. This suggests that more of the available resources were allocated within the cued object than across space to the other object. This basic effect has been replicated many times using the same target detection paradigm (e.g., Abrams & Law, 2000; Lamy & Egeth, 2002). However, other researchers have demonstrated that object-based evidence only tends to appear in discrimination tasks rather than in simple target detection tasks (Brawn & Snowden, 2000; Vecera & Farah, 1994). Despite the common belief that object parsing may be preattentive, some evidence suggests that object representations require a period of processing time (e.g., Law & Abrams, 2002). Brawn and Snowden (2000) suggested that target detection tasks did not tend to make use of object representations as they happened very early in the perceptual processing of a scene. If Egly et al.'s findings were not due to perceptual grouping, as suggested by Brawn and Snowden, what other explanation can there be?

Avrahami (1999) replicated Egly et al.'s (1994) procedure with the exception that straight parallel lines were presented instead of rectangles. These lines ran from one edge of the screen to the other. The equivalent of a within-object, invalid target appeared within the same parallel lines, while the equivalent between-object targets were separated from the cue across the parallel lines. This small manipulation produced the same object bias effect. Avrahami therefore argued that the redirection of attention was achieved via the grain of the displayed image (i.e., the parallel lines) rather than the presentation of objects per se. Thus, attention merely used the straight lines across the screen as a vector to guide an attentional shift.

The "line tracing" paradigm of Jolicœur and colleagues offers further support for Avrahami's findings (Jolicœur & Ingleton, 1991; Jolicœur, Ullman, & Mackay, 1986, 1991). Jolicœur presented participants with two convoluted lines and required participants to judge whether two target dots were presented on the same or on different lines. He found that response times to targets on the same line slowed with the increased separation of the targets along the line, despite the targets being separated by a constant Euclidian distance. Over a series of studies Jolicœur concluded that an automatic "attentional operator" traced the lines from one target to the other.

The present experiments attempted to assess whether another commonly cited example of object-based attention (Lavie & Driver, 1996) could be mediated by a straight line guiding attention between two targets. Lavie and Driver (1996) used a two-target discrimination task rather than a target detection task. They presented participants with two overlapping straight lines, each subtending approximately 12° of visual angle. The lines were supposedly parsed as distinct objects on the basis of good continuation and colour, with one line made up of green dashes and the other line made up of red dashes. Two target elements would occur either within the same line or on different lines, and participants had to indicate whether the targets were the same or different. Results showed that response times were reduced for trials where targets appeared in the same object (line). This was interpreted as support for object-based attention and has been replicated several times (Lamy, 2000; Law & Abrams, 2002). However, in a series of five experiments we show that this effect is abolished or greatly reduced if the two targets are separated by a corner or angle of the object, suggesting that collinearity between targets is an important mediating factor in the effect. In the final experiment, we demonstrate that collinearity between targets is in fact more important than object parsing by colour as was intended in the initial Lavie and Driver (1996) studies.

EXPERIMENT 1

In Experiment 1 we followed the procedure of Lavie and Driver (1996) looking to replicate the basic finding. Participants made a speeded response to two target elements that appeared either within a single line or on two lines. Although Lavie and Driver found a response-time advantage for targets presented within a single object, this facilitation did not manifest itself in terms of greater accuracy of response, as accuracy was close to ceiling. In order to make the task more difficult we presented a mask that terminated the targets but left the form of the two lines remaining. This was aimed at making the procedure more sensitive to any accuracy effect.

Method

Participants
A total of 17 participants took part in the experiment (mean age 26 years; 9 were female). All reported normal or corrected-to-normal vision.

Stimuli and apparatus
The stimuli were composed of one horizontal red line made up of 15 dashes, presented in the centre of the display, and a green, dashed line overlaid on the red line but rotated by an angle of 15° clockwise about its midpoint (Figure 1). The dashes of the horizontal line subtended 0.52° and were separated by gaps of 0.27°. In total the horizontal line measured 11.4°. The rotated line also contained 15 dashes of the same length, though the gap between the dashes was increased giving an overall length of 12.1°. All lines were 0.04° thick. Target elements were either the absence of one of the dashes or the replacement of one with a dot. One of the target elements replaced a dash that was third from the end of a line while the other element replaced a dash that was fourth from the end of a line. This was done in order to avoid any bias due to display symmetry. The mask was simply the replacement of the two lines with two similar lines with dashes of higher spatial frequency. These smaller dashes were approximately 0.13° in length. The colours of the mask lines were the same as those of the premask lines. These stimuli were presented

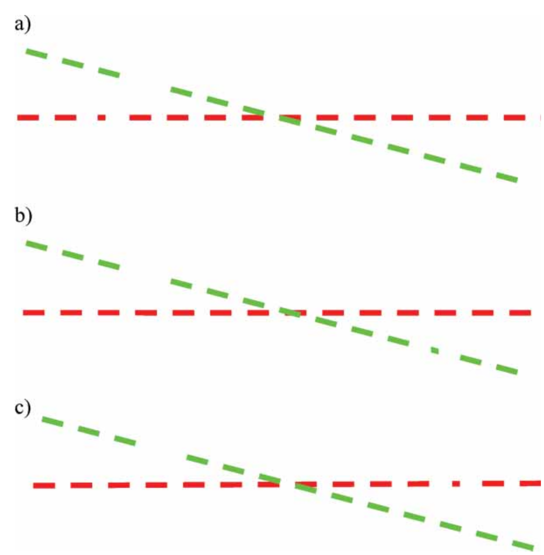

Figure 1. *Stimulus displays used in Experiment 1 depicting (a) the "near" condition, (b) the "object" condition, and (c) the "far" condition. All three show the "different target" condition.*

against a uniformly grey background. The experiment was carried out in a single dimly lit room and was driven by a Pentium 3 PC linked to a standard colour monitor.

Design and procedure

A within-participant, two-factor procedure was used. The "target parity" factor manipulated whether the two targets in the display were the same (either two dots or two gaps) or different (a dot and a gap). The second factor of "target configuration" manipulated whether the two targets occurred within the same line (the "object" condition), on different lines but close to each other in Euclidean space (the "near" condition), or on different lines but far from each other (the "far" condition; see Figure 1). These conditions replicated those used in the initial Lavie and Driver study (1996). Each trial began with the presentation of a fixation point for 1,000 ms before the appearance of the two lines and targets for 177 ms. The mask then appeared until the participant responded by pressing a key on the keyboard to indicate that the two target elements were either the same ("2" on the numerical keypad) or different ("0"). Participants were seated 90 cm from the display. Their speeded responses were inputted via a standard keyboard and were followed by visual feedback. A practice block of 48 trials preceded the experiment. There were 624 experimental trials split evenly across the six conditions, presented randomly in blocks of 48 trials.

Results and discussion

As with Lavie and Driver (1996) all reaction times (RTs) under 200 ms or over 2,000 ms were removed as outliers prior to analysis of correct RTs. This amounted to 5% of scores removed as outliers. All means for Experiment 1 are reported in Table 1.

Condition means for each participant were entered into a 2 × 3 within-participant analysis of variance (ANOVA). A significant main effect was observed for target parity, $F(1, 16) = 22.8$, $MSE = 9{,}027$, $p < .001$, as well as a significant main effect of target configuration, $F(2, 32) = 25.1$, $MSE = 449$, $p < .001$. The interaction between the two factors was also significant, $F(2, 32) = 4.7$, $MSE = 673$, $p < .05$. This interaction demonstrates that the RT advantage observed for targets presented in the "object" condition (compared with "near" and "far" conditions) was greater when the two targets were the same. Collapsing across the two target parity conditions, planned contrasts were carried out between the object and near conditions, and the object and far conditions. Both comparisons proved to be significant with targets in the object condition responded to fastest, $F(1, 16) = 49.8$, $MSE = 22{,}560$, $p < .001$, and $F(1, 16) = 15.4$, $MSE = 6{,}329$, $p < .005$, respectively.

The analysis of percentage accuracy scores revealed significant main effects for target parity, $F(1, 16) = 8.0$, $MSE = 61.5$, $p < .05$, and target configuration, $F(2, 32) = 14.6$, $MSE = 27.5$, $p < .001$. The interaction was, however, not significant, $F(2, 32) = 2.0$, $MSE = 44.7$, $p < .2$. Both the main effects have therefore replicated the results observed with the RT data. As with RTs, we collapsed across the two target parity conditions and carried out planned contrasts between the object and near conditions, and the object and far conditions. Although the first contrast proved to be significant, with more accurate responses for targets in the same object, $F(1, 16) = 22.9$, $MSE = 34.4$, $p < .001$, the second contrast narrowly failed to reach conventional statistical significance, $F(1, 16) = 4.2$, $MSE = 26.3$, $p < .057$.

Overall, the RT data have closely replicated those of Lavie and Driver (1996) with faster RTs in the object condition reflecting a processing benefit when the two targets were located within a single object. This effect was nominally observed with accuracy scores as well, with marginally greater accuracy for targets appearing within a single object, refuting any possible speed–accuracy trade-off interpretation. These data support Lavie and Driver's object-based account of visual attention.

Initially we had no reason to doubt Lavie and Driver's (1996) object-based explanation for this basic effect, and we designed a second experiment using two overlapping dashed chevrons instead of

Table 1. *Response times and accuracy to targets in Experiments 1 and 2*

		Experiment 1			*Experiment 2*	
		Near	*Far*	*Object*	*Between object*	*Within object*
Response times[a]	Same	715 (51)	697 (48)	662 (45)	690 (36)	706 (36)
	Different	793 (52)	777 (51)	774 (53)	731 (37)	739 (36)
Accuracy[b]	Same	80.4 (3.0)	84.1 (2.8)	89.6 (1.5)	81.3 (2.3)	77.1 (2.4)
	Different	77.3 (3.6)	82.0 (2.7)	81.6 (3.3)	70.6 (2.6)	71.1 (2.5)

Note: Standard errors in parentheses.
[a]In ms. [b]In percentages.

lines, with the target elements appearing on two arms of the same or different chevrons. The intention was to validate a series of stimuli, based on the original dashed lines, which would take part in later experiments exploring the effects of foveal demand upon object bias (for which we required stimuli that did not pass through the central fixation point). Our initial hypothesis for Experiment 2 was that the results of Experiment 1 should be replicated with these slightly more complicated stimuli.

EXPERIMENT 2

Experiment 2 was similar to Experiment 1 though two overlapping chevrons were used instead of two lines (see Figure 2). All target elements were the same distance from each other (removing the "near/far" distinction) yet they could still appear within a single object, or across two objects. However, the within-object targets were also separated by the internal angle of the chevron. If Experiment 1 demonstrated an object-based effect then the same effect should occur here, regardless of the internal angle. We therefore predicted faster response times to within-object targets.

Method

Participants
A total of 16 participants were recruited (mean age 20.2 years; 9 were female). All participants had normal or corrected-to-normal eyesight.

Stimuli and apparatus
The stimuli were comprised of two objects: an orange chevron (18.4 cd/m^2) and a purple chevron (4.5 cd/m^2) made up from dashed lines. These colours were roughly equiluminant from the grey background (11.8 cd/m^2). Each whole dash was 19 pixels in length and 4 pixels in width, and 14 dashes made up the top and bottom arms of each chevron. The two straight

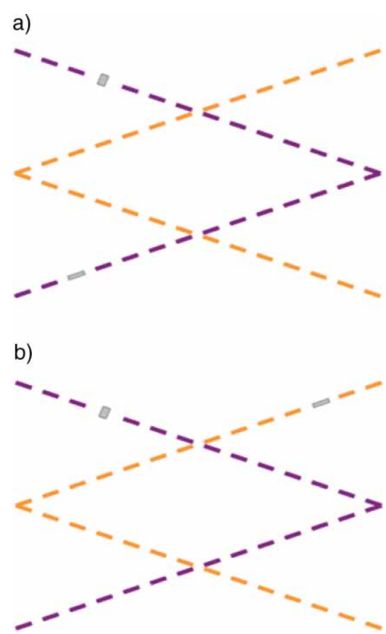

Figure 2. *The stimuli used in Experiment 2. Figure 2a shows the two targets located within a single object, and Figure 2b shows the two targets located between two objects.*

components of each chevron were joined by a corner dash with an angle of 21°. The two chevrons overlapped and together subtended 12.4° of visual angle from one outward-facing point to the other. The height of the display subtended 9.8° at its highest point between the two ends of a chevron. The target elements were either a grey dash (56.7 cd/m^2) of the same dimensions as the orange or purple dash that it replaced, or a fatter, shorter grey block (6 pixels by 13 pixels) that appeared in the centre of the space vacated by the previous dash. These targets could appear in place of either the third or the fourth dash from the end of each of the four lines that made up the chevrons. Whenever two targets appeared together they would be found either on different arms of the same chevron or in different chevrons. Regardless of whether the targets were presented in the same chevron or different chevrons, they were always approximately 7.8° apart. Two targets would never both appear in place of the third dash or the fourth dash on different lines. Instead the targets alternated in their third/fourth dash locations (see Figure 2 for examples of the within-object and between-object stimuli). This was included in order to remove any symmetry effects created by the target locations in relation to the overall pattern (cf. Lavie & Driver, 1996; Saiki, 2000). The stimuli were preceded by a fixation cross and were followed by a mask until response and then by visual feedback. Apparatus was the same as that used in Experiment 1.

Design and procedure

The two within-participant factors were target parity and target configuration as in Experiment 1, though the latter factor was reduced to two levels: within-object and between-object targets. There were 10 blocks of stimuli (half vertically and half horizontally oriented) each containing 64 trials, and 1 practice block with 32 stimuli. Blocks and trials were randomized. All participant instructions referred to the stimuli as two overlapping chevrons.

Results and discussion

Response times below 200 ms and above 2,000 ms were removed (1.5% of responses). Table 1 contains overall mean correct RTs for each of the four conditions. A 2 × 2 within-participant ANOVA revealed a main effect for target parity, with *same* responses faster than *different* responses, $F(1, 15) = 13.0$, $MSE = 1{,}671$, $p < .005$, but no such effect occurred for target configuration, $F(1, 15) = 3.3$, $MSE = 727$, $p < .1$. The interaction was not significant either, $F(1, 15) < 1$. Analysis of accuracy scores revealed the same pattern of results: *Same* responses were more accurate, $F(1, 15) = 18.2$, $MSE = 62.3$, $p < .001$, but there was no effect of target configuration, $F(1, 15) = 3.0$, nor any interaction, $F(1, 16) = 2.6$.

The surprising aspect of these data is the absence of a target configuration effect, despite the design being very similar to that of the previous experiment, which demonstrated object bias. Several pilot studies were subsequently undertaken, varying the number and type of targets, but the object bias could still not be found despite still being perceived as two objects (according to debriefed participants). The research agenda then changed from developing stimuli for a focused-attention investigation of object bias to an investigation of why the angled chevrons did not produce the same results as the straight lines as used by Lavie and Driver (1996).

As with Avrahami's (1999) interpretation of Egly et al.'s (1994) findings, it was therefore possible that the results from Experiments 1 were due to the collinearity of the targets rather than parsing of the object per se. Experiment 2 did not give within-object targets any collinearity advantage over between-object targets, which could explain the failure to find faster RTs for the within-object condition. However, any such conclusions based on null effects are always open to criticisms of power limitations. In order to test the collinearity hypothesis directly a comparison must be made between within-object targets that are both collinear and noncollinear within the same experiment. This was the rationale for Experiment 3.

EXPERIMENT 3

Experiment 3 used new stimuli composed of two overlapping Zs made up of dashed lines to test the collinearity hypothesis (see Figure 3). The rationale for the experiment was to show the within-object effect (observed in Experiment 1) and its abolishment (observed in Experiment 2) within a single experiment, due to the manipulation of target collinearity.

The overlapping Zs allowed comparison of the two targets presented between objects (one target in each Z) with two targets presented within object (both targets appearing in one Z, but separated by an angle) and targets presented within line (both targets again appearing in one Z). It was predicted that if Lavie and Driver's (1996) results were due to the collinearity of the targets, rather than the grouping of the dashes as objects, then an advantage for within-line targets would be noted in comparison to the within-object targets and the between-object targets. If however, Lavie and Driver's results were due to object grouping then both within-line and within-object targets should produce faster RTs than the between-object targets, but should not differ from each other. The within-line and between-object comparison is essentially the comparison that Lavie and Driver categorized as within object and between object.

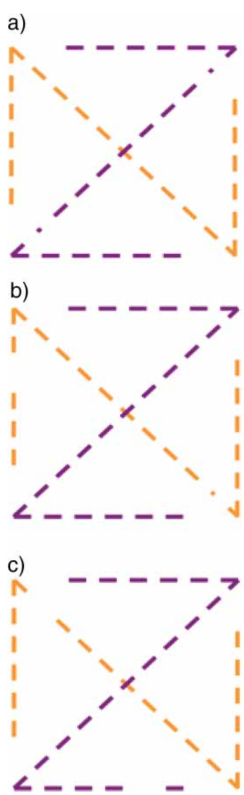

Figure 3. *Examples of stimuli used in Experiment 3. Figure 3a shows a within-line trial, Figure 3b shows a within-object trial, and Figure 3c shows a between-object trial.*

Method

Participants

A total of 15 participants took part in the experiment (mean age 22.3 years; 12 were female). All reported normal or corrected-to-normal vision.

Stimuli and apparatus

A purple Z was presented in an upright orientation. Overlaid on this Z was an orange Z that was rotated by 90° around its midpoint. Each Z subtended 5.7° in height and width and was presented against a grey background (the luminance of the stimuli was the same as that in Experiment 2). Each Z was composed of dashed lines, with 11 dashes forming the longest line and 7 dashes forming each of the two shorter lines. The dashes comprising the Zs were 0.5° long by 0.1° wide and were separated by gaps of 0.25° in length. The exceptions to this were those dashes that joined the intersections, which measured either 0.4° or 0.2° in length. These dashes touched, forming the corners of the Zs. The two target elements were the same as those used in Experiment 1 (gaps and dots) and could occur in 2 of 12 possible locations at a radius of roughly 3° from the point of fixation. This created a nearly equal distance (approximately 5.8°) between the two target elements in each of the three conditions. As with Experiments 1 and 2, a mask was employed, composed of dashed lines with a higher spatial frequency than the stimulus lines, though arranged in the same configuration. Apparatus was the same as that used in Experiment 1.

Design and procedure

A within-participant, 2 × 3 design was employed. As with Experiments 1 and 2, the target parity factor manipulated whether the two targets in the display were the same or different. The second factor of target configuration manipulated the positions of the two targets with respect to the two Zs. Two targets could appear on the same line of the same Z (the longest line spanning fixation; Figure 3a). This was termed the within-line condition. The targets could also appear in the same object but with one target on the shorter arm of the Z (within-object condition, Figure 3b). Finally the targets could appear in separate objects (the between-object condition; Figure 3c). All targets were separated at roughly the same distance from fixation. A total of 64 trials were presented in each of the six conditions, resulting in a total of 384 trials. A practice block of 48 trials preceded the experiment. All other aspects of the procedure were as those described for Experiments 1 and 2. All instructions to participants referred to the stimuli as two overlapping Zs to encourage appropriate parsing of the stimuli.

Results and discussion

Outliers were again omitted from RT analysis resulting in the removal of 2.3% of responses. Condition means are shown in Figure 4. Significant main effects were observed for both target parity, $F(1, 14) = 11.3$, $MSE = 6{,}802$, $p < .005$, and target configuration, $F(2, 28) = 17.8$, $MSE = 1{,}524$, $p < .001$. The interaction was not significant, $F(2, 28) < 1$. Planned contrasts, collapsing across the two target parity conditions, showed that whilst the within-line condition produced faster RTs than did the within-object condition, $F(1, 14) = 26.0$, $MSE = 1{,}416$, $p < .001$, no such effect was observed for a comparison of the within-object and between-object conditions, $F(1, 14) < 1$. The fact that facilitation was observed for targets presented within a single line compared to targets presented between two objects replicates the findings of Lavie and Driver (1996), who reported an object-based effect. However, the inclusion of the within-object condition (unconfounded by collinearity) demonstrated that the true nature of the effect appears to be due, at least in part, to the straight line between the target elements that is present in the within-line condition, but not in the other two conditions.

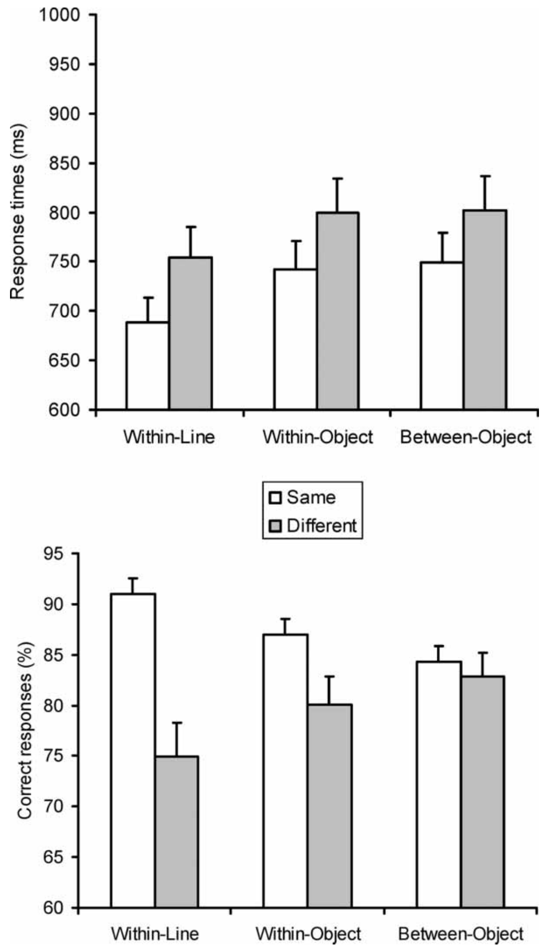

Figure 4. *Results from Experiment 3. In the top panel mean correct RTs are shown for the within-line, within-object, and between-object conditions for both target parity conditions. Mean accuracy detection rates are shown in the bottom panel (with standard error bars).*

Accuracy rates also revealed a significant main effect of target parity, $F(1, 14) = 20.4$, *MSE* = 72.9, $p < .001$, but no main effect of target configuration, $F(2, 28) < 1$. The interaction was significant, $F(2, 28) = 16.2$, $MSE = 25.1$, $p < .001$, with an improvement in accuracy for responses to within-line targets only when the target elements were the same. Responses to different targets were actually worse in the within-line condition than in the other conditions. This is consistent with the accuracy results from Experiment 1 (and Experiment 4) where the target configuration effect is much larger for same-target responses. Unlike the present experiment, however, different-target responses in Experiments 1 and 4 did not nullify the main effect of target configuration. The pattern of results for accuracy is not mirrored in the RT data, and a speed–accuracy trade-off is therefore rejected. The surprising effect of reduced accuracy to different targets contained within the same object does not invalidate the conclusions, but will be returned to later in the General Discussion.

To summarize the findings of Experiment 3, the object-based RT effect noted by Lavie and Driver (1996) appears to be dependent on the two targets being located along a straight line, rather than within the same object per se. The inclusion of an angle in the inducing object removed facilitation for target discrimination.

EXPERIMENT 4

Experiment 4 assessed whether the RT facilitation for straight-line targets is an advantage for targets presented on any straight line, or whether the facilitation only occurs for targets presented within a line that traverses the fixation point. Many researchers have noted the effects of lines upon directing attention (Avrahami, 1999; Jolicœur et al., 1986; Scholte, Spekreijse, & Roelfsema, 2001). If lines are used as vectors for guiding attention, however, then attention must begin from a certain point in the display (regardless of whether attention traces the line in a focal manner or spreads along it; Houtkamp, Spekreijse, & Roelfsema, 2003). The logical starting point is the fixation point, especially if the fixation point falls on a line that can be traced. If this occurs, the within-line targets may have benefited not simply because they were located within the same straight line, but because attention spread outward or started moving from the point of fixation along the two longest straight lines. These targets would therefore be processed sooner, not because they are on a straight line but because they are closest to the fixation point along that line. Experiment 4 replicated the design and procedure used in Experiment 3 with the exception that the two target elements occurred at different locations (see Figure 5). While the Euclidean distance between the two targets and between the targets and fixation was held constant, the linear distance of the targets from fixation was manipulated such that

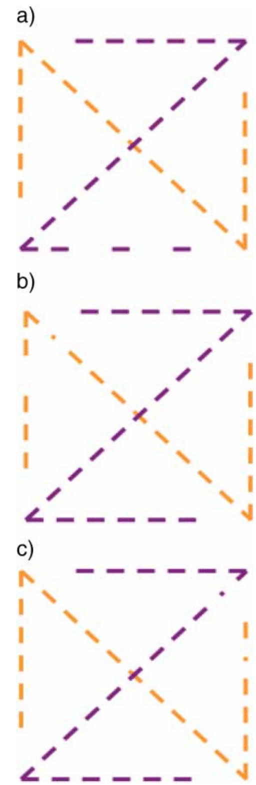

Figure 5. *Examples of stimuli used in Experiment 4. Figure 5a shows a within-line trial, Figure 5b shows a within-object trial, and Figure 5c shows a between-object trial.*

within-object targets were closer to fixation than the within-line targets. If the within-line bias is independent of the point of fixation, the same facilitation noted in Experiment 3 should be replicated. If, however, deployment or movement of attention is constrained by the point of fixation (as Jolicœur might suggest in regard to a line-tracing operator) then the within-object condition should produce the fastest responses.

Method

A total of 15 participants with normal or corrected-to-normal vision took part in the experiment (mean age 26.5 years; 12 were female). Every aspect of the experiment was identical to that of Experiment 3 with the sole exception of the two target positions relative to each other. As demonstrated in Figure 5, within-line targets would only appear on one of the (four) short arms of the two Zs. The two targets of the within-object condition were placed one either side of one of the corners of a Z. Between-object targets were separated by the same distance as the distance between targets that appeared adjacent to each other in the other conditions, but one on either object. The distance between the two targets in all conditions was 1.6°.

Results and discussion

Outliers were again omitted from RT analysis (4.6%). *Same* responses were faster than *different* responses, $F(1, 14) = 9.3$, $MSE = 11{,}692$, $p < .01$, and there was a main effect of target configuration, $F(2, 28) = 8.3$, $MSE = 3{,}094$, $p < .001$. The interaction was also significant, $F(2, 28) = 6.0$, $MSE = 2{,}118$, $p < .01$. Planned contrasts, collapsing across the two target parity conditions, revealed that within-line targets had faster RTs than within-object targets, $F(1, 14) = 4.7$, $MSE = 3{,}989$, $p < .05$, but the within-object/between-object difference did not reach significance, $F(1, 14) = 3.3$. These data have closely replicated the effects on response times noted in Experiment 3, with the addition of a significant interaction. As we noted in Experiment 1, the reason for this is that the strength of the target configuration effect is much stronger when the two targets are the same (see Figure 6).

Same responses were also more accurate than *different* responses, $F(1, 14) = 17.0$, $MSE = 225$, $p < .001$, and there was a target configuration effect, $F(2, 28) = 29.3$, $MSE = 32.7$, $p < .001$, as well as a significant interaction, $F(2, 28) = 26.5$, $MSE = 40.6$, $p < .001$; see Figure 8. Planned contrasts revealed that responses to within-line targets were more accurate than those to within-object targets, $F(1, 14) = 23.6$,

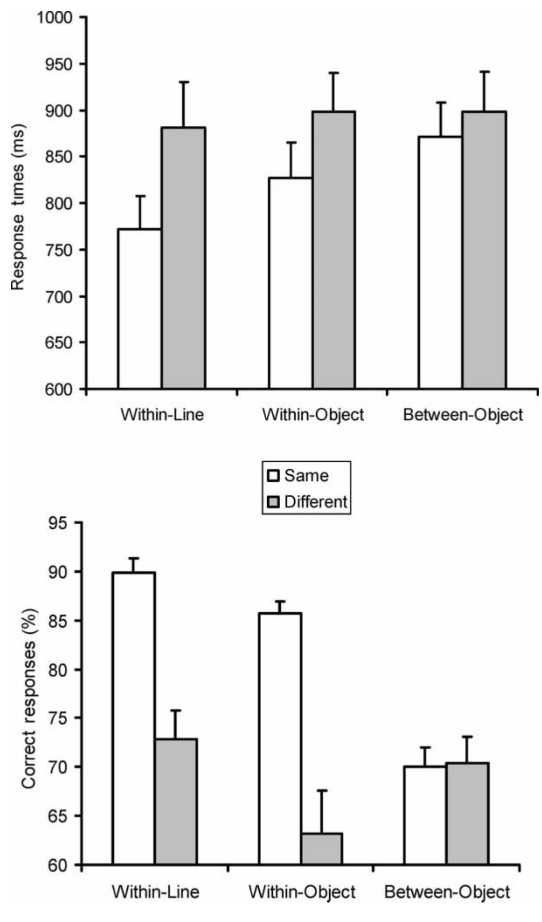

Figure 6. *Results from Experiment 4. In the top panel mean correct RTs are shown for the within-line, within-object, and between-object conditions for both target parity conditions. Mean accuracy detection rates are shown in the bottom panel (with standard error bars).*

MSE = 30.9, $p < .001$, and responses to within-object targets were more accurate than those to between-object targets, $F(1, 14) = 5.9$, *MSE* = 45.3, $p < .05$. The interaction reinforces the finding that this effect is stronger for targets requiring a *same* response, but also draws attention to the fact that though responses to within-line targets are more accurate than those to within-object targets, responses to within-object targets are still considerably more accurate than responses to between-object targets when the targets are the same.

In summary, once again an RT advantage has been observed for targets presented within a single object compared to targets presented between two objects. However, as with Experiment 3, this effect only occurred when the two targets were located along a straight line. No within-object facilitation was observed when the targets were located either side of an angle. These findings were also observed when accuracy rates were analysed, though the accuracy data also revealed a smaller benefit for within-object targets than for between-object targets.

The data therefore show that the processing advantage for within-line targets does not depend upon the straight line traversing the fixation point, which reinforces the argument that the null results of Experiment 2 were particular to the angle that was introduced into the stimuli. There is, however, still some evidence of object bias in the accuracy data of Experiment 4, though across all experiments this is neither as strong nor as stable as the collinearity effect.

EXPERIMENT 5

In a final experiment we set out to demonstrate that the collinearity of targets could reverse the object bias effect as reported in Lavie and Driver (1996). For this experiment, the original stimuli used in Experiment 1 were modified to provide three object conditions. The first condition contained the original overlapping dashed lines used by Lavie and Driver. Two other conditions changed the perceptual grouping of the objects by varying the colour of the two halves of the dashed lines. This produced conditions where targets could appear in a straight line, while appearing to be in separate objects (at least when judged by colour, see Figure 7). It was predicted that if collinearity was the overriding factor in the original Lavie and Driver study (1996), then the object bias should be reversed to favour between-object targets, providing that they are presented collinearly.

Method

Participants

A total of 9 participants were recruited to take part in the experiment (mean age 24.6 years, 3 female). All reported normal or corrected-to-normal eyesight.

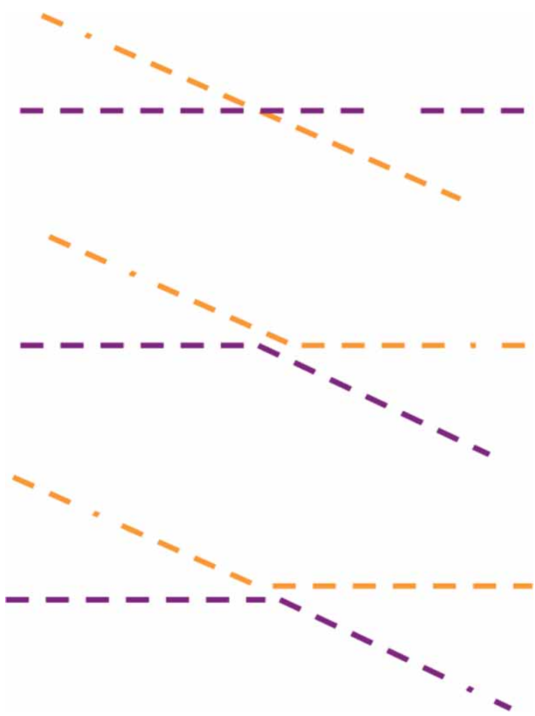

Figure 7. *Examples of stimuli used in Experiment 5. The top panel is from the original stimulus condition, requiring a different response to between-object targets. The middle panel is taken from the horizontal condition and requires a same response to within-object targets. The bottom panel is an example of the vertical condition, requiring a same response from between-object targets.*

Stimuli and apparatus

The stimuli for the *original* condition were composed of one horizontal purple line made up of 18 dashes, presented in the centre of the display, and an orange dashed line overlaid on the purple line and rotated by an angle of 15° clockwise about its midpoint. Two further conditions used kinked lines (lines that contained an angle) composed of dashes of the same colour. The angle was 165°, and the two objects were aligned so that either the horizontal portions of the two objects were collinear (the horizontal condition) or the vertical or oblique portions of the objects were collinear (the vertical condition; see Figure 7). A distinction was made between the horizontal and vertical conditions because a stimulus could not be created that maintained the same length of gaps between dashes and preserve collinearity between both the vertical and the horizontal portions of the lines at the same time. The colours and luminance of the lines and the background were the same as those used in Experiments 2 to 4. The dashes of the horizontal line subtended 0.64° and were separated by gaps of 0.32°. Thus in total the horizontal line measured 17.5°, which is closer to the original dimensions used by Lavie and Driver (1996) than the visual angle subtended by the stimuli in Experiment 1. The rotated line also contained 18 dashes of the same length. All lines were 0.04° thick. Target elements were either the absence of one of the dashes or the replacement of one with a dot. Targets replaced either the second or the third dash from the end of a line to control for symmetry effects, as with previous experiments. A higher spatial frequency mask was used, which retained the colours of the two objects. All apparatus was the same as that in previous experiments.

Design and procedure

A within-participant, 2 × 2 × 3 design included the factors of target parity (same or different), object condition (within or between objects), and the collinearity condition (using original, horizontal, and vertical-collinear variations of the stimuli). A practice block of 32 trials preceded 18 randomly presented experimental blocks. A total of 576 experimental trials were presented. All instructions were the same as those in previous experiments.

Results and discussion

After removing outlying response times less than 200 ms and greater than 2,000 ms (6.4%), the response times were subjected to a 2 × 2 × 3 ANOVA. No main effects were noted though there was an interaction between all three factors, $F(2, 16) = 3.8$, $MSE = 4{,}795$, $p < .05$. Simple main effects analyses separated the same responses from the different responses with two 2 × 3 ANOVAs. These revealed that the interaction between the collinearity and object conditions was only significant with same responses, $F(2, 16) = 6.6$, $MSE = 5{,}830$, $p < .01$. None of the effects with the different responses reached statistical significance.

As with previous analyses we collapsed the parity factor to allow planned contrasts between the other factors. The planned contrasts compared the RTs to within-object and between-object trials with the original stimuli against the mean of the vertical and horizontal trials, and they also compared the horizontal trials directly to the vertical trials. A significant effect was found when comparing the response times with the original stimuli to the mean of the horizontal and vertical trial response times across the object factor, $F(1, 8) = 33.9$, $MSE = 1{,}718$, $p < .001$. As can be seen in Figure 8, the object-based effect is present in the original stimuli, post hoc t test, $t(8) = 4.9$, $p < .01$, but this effect is reversed in the horizontal condition, where targets that are in separate objects (yet are horizontally collinear) are responded to faster, $t(8) = 2.9$, $p < .05$. The effect upon the vertical trials is less pronounced, and although one cannot suggest that the vertical trials show a definitive benefit for collinear targets over within-object targets, neither is there any evidence for object bias.

Analysis of accuracy revealed three interactions. An interaction was noted between the collinearity condition and whether the targets appeared in the same object or not, $F(2, 16) = 5.4$, $MSE = 99.9$,

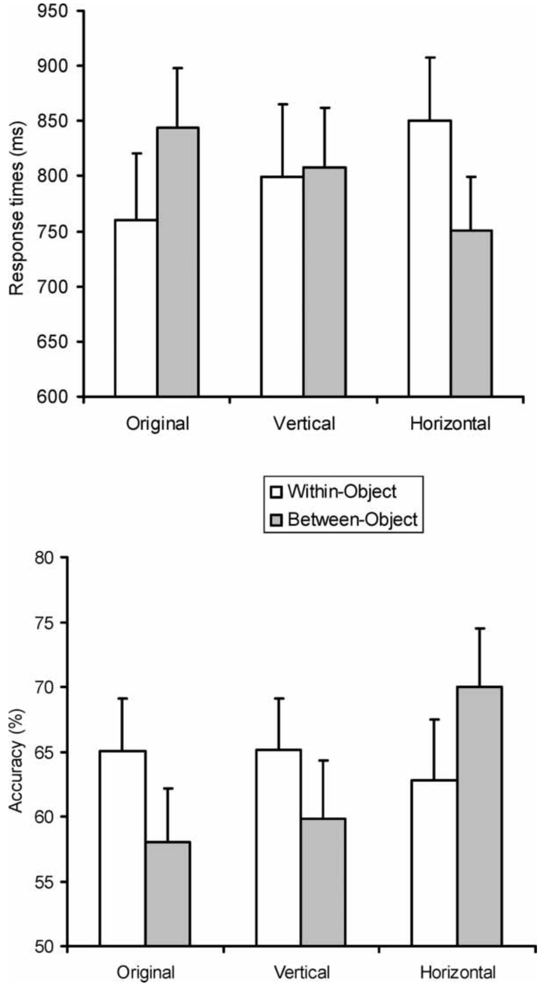

Figure 8. *Results from Experiment 5. In the top panel are mean response times to within and between-object targets on the original stimuli and on both horizontally and vertically collinear stimuli. Mean accuracy detection rates are shown in the bottom panel (with standard error bars).*

$p < .05$. Preplanned contrasts compared the horizontal and vertical conditions, $F(1, 8) = 5.9$, $MSE = 240$, $p < .05$, and the mean of the horizontal and vertical conditions to the original stimuli condition, $F(1, 8) = 4.8$, $MSE = 119$, $p = 0.06$. These comparisons reflected the fact that though there was little difference between the accuracy rates for the vertical and original conditions, the between-object targets in the horizontal condition were correctly identified more often (Figure 8).

A second two-way interaction was noted between the object condition and whether the targets were the same or different, $F(1, 8) = 32.1$, $MSE = 28.0$, $p < .001$. This reflected the greater benefit of same targets on accuracy in the within-object condition (68% accuracy with the same targets compared to 60% with different targets). No benefit was noted for same targets in the between-object condition (with 61% and 64% accuracy, respectively).

A three way interaction between all variables was also significant, $F(2, 16) = 181$, $MSE = 48.6$, $p < .05$. To investigate this further, data from the horizontal, vertical, and original stimuli were analysed independently. Only the original stimuli revealed a significant interaction between object condition and target parity, $F(1, 8) = 13.8$, $MSE = 72$, $p < .01$, reflecting an object bias that only occurred for same targets (Figure 9).

The results of this experiment replicate those of Experiment 1 and those of Lavie and Driver (1996) using the original stimuli. These stimuli produce RT and accuracy benefits for two targets that appear within the same object (and also along the same straight line), with *same* responses benefiting most. However, when using the kinked

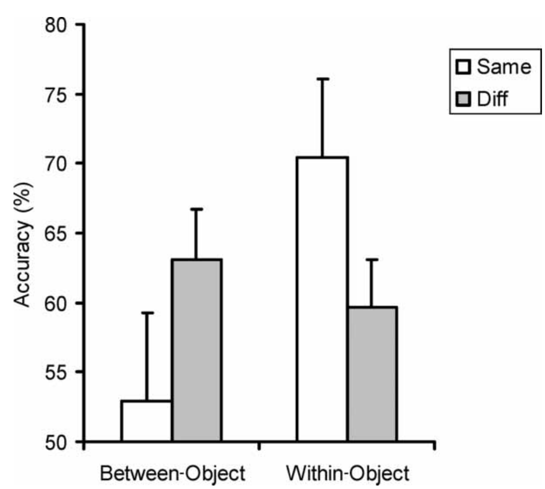

Figure 9. *Mean accuracy detection rates for the original stimuli condition (with standard error bars).*

stimuli the object bias disappears in terms of accuracy and is actually reversed with regard to RTs, with targets located in different objects (according to the colour segmentation used by Lavie & Driver, 1996) producing the fastest RTs. This result contradicts the conclusion that the original stimuli produce a facilitation due to the two stimuli being perceived as separate objects. Instead it suggests that the collinearity of the two targets is important in producing the benefits that have previously been considered to reflect object bias.

GENERAL DISCUSSION

Five experiments have been reported assessing the mechanism that mediates the basic within-object facilitation reported by Lavie and Driver (1996) and replicated by Lamy (2000). Stimulus displays showed two target elements located either within a single object or across two objects. Participants decided as quickly as possible whether the targets were the same or different. In Experiment 1 we demonstrated the basic effect reported by Lavie and Driver. RTs were reduced when the targets appeared within a single object relative to when they appeared across two objects. This within-object facilitation was abolished in Experiment 2 when a corner or angle was introduced along the line containing the two targets. Experiment 3 replicated the results from Experiments 1 and 2 within a single experiment. Although an RT advantage was observed for targets occurring within a single object, this facilitation was only seen when both targets appeared in a straight line. Again when a corner separated the targets no within-object facilitation occurred. Experiment 4 assessed whether the straight-line effect is dependent upon the straight line traversing the fixation point. Results showed that it was not. The final experiment attempted to reverse object bias by presenting targets that were collinear though they appeared in different objects. The results suggested that collinear between-object targets could produce faster RTs than could within-object targets. The accuracy rates were also reversed, though only in the horizontal condition.

One study has, however, demonstrated object bias with angled objects, which goes against the current results. Behrmann et al. (1998) asked participants to compare the ends of two overlapping V-shaped objects. They found faster response times for stimuli where the two targets were contained within the same object, even when the object was occluded by an overlapping object. Saiki (2000), however, suggested that there was a strong possibility that the object bias was confounded with the symmetry of the objects. When Saiki removed this symmetry confound the object bias disappeared also. On this basis we argue that Behrmann et al.'s results do not necessarily contradict the current results, which controlled for symmetry following the guidelines of Lavie and Driver (1996).

Overall, the current results suggest that Lavie and Driver's (1996) within-object effect, rather than being solely due to perceptual grouping of the stimuli, may have in fact been mediated by the collinearity of the two targets. This suggests that object-based effects that are found with collinear targets may overestimate the grouping effect. This supports and extends the work of Avrahami (1999), who also showed that a previously reported example of object bias in a target detection paradigm (Egly et al., 1994) was mediated by the orientation of features, with linear vectors providing the target facilitation, rather than a Gestalt grouping principle. The majority of Avrahami's experiments were, however, concerned with target detection. While some researchers believe that early object representations can influence the response times to target detections (e.g., Lamy & Egeth, 2002; Lamy & Tsal, 2000) there is evidence that only tasks that involve some form of discrimination between two targets invoke object representations (e.g., Brawn & Snowden, 2000). Avrahami (1999) has demonstrated that at least some of those previous experiments that have produced object effects with target detection may have been due to low-level collinearity. The current results extend this hypothesis, suggesting that even discrimination tasks may fail to produce object-based effects when collinearity is controlled for.

Clearly, all object-based accounts of attention cannot be questioned on the basis of the present data. Many other studies have shown object effects without linear confounds. For example, Baylis and Driver (1993) reported object effects merely using perceptual set to distinguish the within-object and between-object conditions. Indeed, even the current data do not completely reject object-based attention. Experiment 4 still demonstrated an accuracy advantage for within-object targets compared to between-object targets. What the current results do demonstrate, however, is that object effects on simple line objects do not transfer to objects that are slightly more complex.

This raises the question of whether the intended objects that were slightly more complex (chevrons, Zs, and kinked lines) were seen as objects, or whether the parsing of the scene occurred at a lower level (with perhaps each straight segment being parsed as an individual entity). We argue that while there is evidence that the parsing of complex stimuli as objects or as parts of objects can be determined by discontinuities in shapes and lines (Watson & Kramer, 1999), this does not detract from the current critical appraisal of the stimuli used by Lavie and Driver (1996) and others. Though it is possible that the current complex stimuli were not perceived as two objects, despite instructions to the participants reinforcing the two-object interpretation of the scene, and despite participants' continual references to two objects during debriefing sessions, the criticism against the use of simple collinear objects remains valid. If object effects can only be found with collinear objects, but not with slightly more complex objects, then we would have to either redefine what an object is or reconsider the mechanism underlying within-object facilitation. Many studies of object bias have used simplistic stimuli such as lines or rectangles, but the studies reported here and those of Avrahimi (1999) argue that we should increase the complexity of these "objects" if we are ever to understand object processing in the real world (see O'Grady & Müller, 2000).

One further consideration is that though collinearity may have confounded previous studies, it could actually play a part in an object-parsing process (Scholl, 2001). Many researchers have demonstrated that curvature and collinearity can be processed in parallel under some conditions (Fahrl, 1991, Field, Hayes, & Hess, 1993; Kovács & Julesz, 1993), yet when lines are more convoluted attention acts in a serial fashion (Jolicœur et al., 1986, Roelfsema, Lamme, & Spekreijse, 2000; Scholte et al., 2001). Scholte et al. (2001) offer a distinction between two processes to account for both parallel and serial object parsing. The first process they term *base grouping*, which describes the immediate grouping of features for which we have shape-selective cells in the visual cortex. Quite complex shapes can be processed in this manner by specifically attuned neurons that are sufficiently high in the processing hierarchy. When faced with novel stimuli, however, a second process is required called *incremental grouping*. In this process attention spreads across the features of an object, binding them into a coherent object representation.

Collinearity may provide input into the base grouping process, especially when an object can be defined for the purposes of a task solely in these terms. It has, however, been argued that curvillinearity (or simply good continuation through curves or angled straight lines) may be important for incremental grouping (Houtkamp et al., 2003), with attention moving or spreading along these lines in order to produce an object representation. In this latter case one might suggest that object-based facilitation might have been found for the more complex stimuli if they were available for longer to allow incremental grouping. However the line-tracing tasks used by Jolicœur et al. (1986) can be performed within stimulus presentation times similar to those used in the current studies, and even if object-based facilitation was found with longer stimulus onset asynchronies it would not change the general conclusion that the stimuli and presentation times used by Lavie and Driver (1996), Lamy (2000), and Law and Abrams (2002) were too impoverished to provide an understanding of what it means to attend to an object.

There are still unanswered questions regarding the contribution of collinearity to this target discrimination paradigm, however. For instance, why should the facilitation be stronger for *same* responses than for *different* responses? Collinear features in the real world are more likely to be the same rather than different (as this is a key factor in any grouping process), so the fact that two targets appear in the same line may prime a *same* response. To have two different targets appear in a straight line might even reflect a form of Stroop effect, where collinearity suggests that the two targets should be the same while the targets themselves contradict this. Figure 5 fits this pattern with reduced accuracy for different targets in the within-line condition, possibly reflecting the Stroop-like interference of our expectations of collinearity. The data are not convincing enough to draw this conclusion yet, though they do suggest an interesting avenue for further research.

Whatever the relationship between collinearity and real-world object parsing, these results have demonstrated that certain previous evidence for object-based attention in two-target discrimination tasks is confounded with the collinearity of the targets.

Original manuscript received 12 July 2005
Accepted revision received 16 February 2006
First published online 5 May 2006

REFERENCES

Abrams, R. A., & Law, M. B. (2000). Object-based visual attention with endogenous orienting. *Perception & Psychophysics, 62*, 818–833.

Avrahami, J. (1999). Objects of attention, objects of perception. *Perception & Psychophysics, 61*, 1604–1612.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 451–470.

Behrmann, M., Zemel, R. S., & Mozer, M. C. (1998). Object-based attention and occlusion: Evidence from normal participants and a computational model. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1011–1036.

Brawn, P. T., & Snowden, R. J. (2000). Attention to overlapping objects: Detection and discrimination of luminance changes. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 342–358.

Cole, G. G., Kentridge, R. W., & Heywood, C. A. (2004). Visual salience in the change detection paradigm: The special role of object onset. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 464–477.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 448–456.

Duncan, J. (1984). Selective attention and the organization of visual attention. *Journal of Experimental Psychology: General, 113*, 501–517.

Egly, R., Driver, J., & Rafal, R. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*, 161–177.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143–149.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*, 225–240.

Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 583–597.

Fahrl, M. (1991). Parallel perception of vernier offsets, curvature, and chevrons in humans. *Vision Research, 31*, 2149–2184.

Field, D. J., Hayes, A., & Hess, R. F. (1993). Contour integration by the human visual system: Evidence for a local "association field". *Vision Research, 33*, 173–193.

Gellatly, A. R. H., & Cole, G. G. (2000). Accuracy of target detection in new object and old object displays. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 889–899.

Gellatly, A. R. H., Cole, G. G., & Blurton, A. (1999). Do equiluminant objects capture visual attention?

Journal of Experimental Psychology: Human Perception and Performance, 25, 1609–1624.

Houtkamp, R., Spekreijse, H., & Roelfsema, P. R. (2003). A gradual spread of attention during mental curve tracing. *Perception & Psychophysics, 65*, 1136–1144.

Jolicœur, P., & Ingleton, M. (1991). Size invariance in curve tracing. *Memory and Cognition, 19*, 21–36.

Jolicœur, P., Ullman, S., & Mackay, M. (1986). Curve tracing: A possible basic operation in the perception of spatial relations. *Memory and Cognition, 14*, 129–140.

Jolicœur, P., Ullman, S., & Mackay, M. (1991). Visual curve tracing properties. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 997–1022.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181–211). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24*, 175–219.

Kovács, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure–ground separation. *Proceedings of the National Academy of Sciences, USA, 90*, 7495–7497.

Lamy, D. (2000). Object-based selection under focused attention: A failure to replicate. *Perception & Psychophysics, 62*, 1272–1279.

Lamy, D., & Egeth, H. (2002). Object-based selection: The role of attentional shifts. *Perception & Psychophysics, 64, 1*, 52–66.

Lamy, D., & Tsal, Y. (2000). Object features, object locations and object files: Which does selective attention activate and when? *Journal of Experimental Psychology: Human Perception and Performance, 26*, 1387–1400.

Lavie, N., & Driver, J. (1996). On the spatial extent of attention in object. *Perception & Psychophysics, 58*, 1238–1251.

Law, M. B., & Abrams, R. A. (2002). Object-based selection within and beyond the focus of spatial attention. *Perception & Psychophysics, 64*, 1017–1027.

O'Grady, R., & Müller, H. J. (2000). Object-based selection operating on a grouped array of locations. *Perception & Psychophysics*, *62*, 1655–1667.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Roelfsema, P. R., Lamme, V. A. F., & Spekreijse, H. (2000). The implementation of visual routines. *Vision Research, 40*, 1385–1411.

Saiki, J. (2000). Occlusion, symmetry, and object-based attention: Comment on Behrmann, Zemel, and Mozer (1998). *Journal of Experimental Psychology: Human Perception and Performance, 26*, 424–433.

Scholl, B. J. (2001). Objects and attention: The state of the art. *Cognition, 80*, 1–46.

Scholte, H. S., Spekreijse, H., & Roelfsema, P. R. (2001). The spatial profile of visual attention in mental curve tracing. *Vision Research, 41*, 2569–2580.

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centred inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology, 43A*, 289–298.

Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: General, 123*, 146–160.

Watson, S. E., & Kramer, A. F. (1999). Object-based visual selective attention and perceptual organization. *Perception & Psychophysics, 61*, 31–49.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 95–107.