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Allocating visual attention to grouped objects

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The purpose of the present study is to examine the allocation of visual attention to independent stimuli that are grouped together through a set of Gestalt principles. The basic display used in the experiments consisted of a 4 × 4 matrix of placeholders, made up of 12 circles and 4 squares. In Experiment 1, the squares were located adjacent to each other (i.e., perceptually grouped together), whereas in Experiment 2 the squares were located in nonadjacent locations (i.e., not perceptually grouped). Following a peripheral cue at a square placeholder, faster detection responses were found for targets appearing in the noncued square placeholders than in corresponding circle placeholders for Experiment 1. This pattern of results was not found in Experiment 2. Experiment 3 used an alternate display to rule out the possibility that the results of Experiment 1 were due to shape-based object priming. Experiment 4 extended the cue–target SOA to examine whether inhibition of return would spread through grouped objects—it did not. These findings provide new insights into the boundary conditions for what, exactly, constitutes an object.

It has long been known that perceptual grouping is a necessary occurrence for perceiving the world around us. For example, Wertheimer (1923/1950) stressed that our visual world would appear chaotic and unorganised if we were unable to organise visual stimuli into a collection of meaningful objects. Since the time of Wertheimer, psychologists have repeatedly demonstrated that visual stimuli are grouped together on the basis of a set of simple ‘‘Gestalt’’ principles (e.g., proximity, similarity, continuity; Han, Humphreys, & Chen, 1999; Kellman, 2000; Weiten, 1995; Wertheimer, 1923/1950).

There is considerable evidence indicating that if one portion of an object is cued (and therefore attended to), then attention will be allocated to the entire object (e.g., Abrams & Law, 2000; Egly, Driver, & Rafal, 1994a; Egly, Rafal,

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Driver, & Starrveld, 1994b; Vecera & Farah, 1994). For example, Egly et al. (1994a) used a visual display consisting of two parallel rectangles and presented a cue at one end of one rectangle. Following the cue, a detection target appeared at either the cued end of the cued rectangle (80% probability), the uncued end of the cued rectangle (10%), or the adjacent end of the uncued rectangle (10%). Comparing the two uncued ends, RTs were faster for targets on the cued rectangle than the uncued rectangle, even though both target locations were equally distant from the cue. Egly et al. interpreted this finding as an object-based attention effect, where an entire object is attended to even if attention is only directed (via a cue) to a portion of that object.

Moore, Yantis, and Vaughan (1998) replicated and extended Egly et al. (1994a) by adding conditions in which the middle portions of the two rectangles were occluded, or rectangles were defined by subjective contours. As before, the object-based advantage for targets at the uncued end of a cued, but occluded, rectangle occurred, indicating that visual attention is allocated throughout perceptually completed objects. Moreover, there is evidence that observers allocate attention throughout perceptually completed objects even when prior experience dictates that completion should not take place (Pratt & Sekuler, 2001). These findings are especially important considering that the objects we typically encounter in the world are often partially occluded.

It is worth noting that there are limits to object-based attention effects produced by the Egly et al. (1994a) paradigm. For example, Avrahami (1999) used a variation of the Egly et al. (1994a) paradigm in which the experimental display consisted of two ribbons (basically the same display as Egly et al. except that the rectangles were bent in the middle) and failed to find a same-object advantage across three experiments despite observing valid cueing effects which were comparable in magnitude to those reported by Egly et al. Even when the cue-target SOA was increased to allow more time for the objects to be processed, there was only a small, nonsignificant, same-object advantage (12 ms). A same-object advantage only emerged when the researchers switched to a different, nonspeeded task. Furthermore, Watson and Kramer (1999) have demonstrated the sensitivity of object-based effects to a number of factors. Using displays consisting of two wrenches (again, similar to the Egly et al. displays), Watson and Kramer manipulated uniform connectedness, as well as the surface characteristics of the wrenches and observed drastic differences in the magnitude of the same-object effect (indeed, in some conditions no same-object effect was observed). These findings (see also Lamy & Egeth, 2002) call into question the generality of the object-based effect reported by Egly et al. (1994a).

There is also considerable evidence that perceptual grouping influences the allocation of visual attention. For example, Prinzmetal (1981) investigated the role of feature integration in visual detection tasks. Using conjunction errors as a measure of feature integration, Prinzmetal demonstrated that observers are likely to integrate items in visual displays that belong to the same perceptual group. In a similar vein, Prinzmetal and Banks (1977) demonstrated an influence of good continuation in a visual task—participants were slower to detect targets when they were grouped with distractors relative to when they were not. Additionally, Treisman (1982; Treisman & Gelade, 1980) suggested that individuals preattentively grouped stimuli as a function of grouping factors and that these grouped units influenced performance on a visual search task. In this manner, individuals scanned visual displays serially between groups rather than between items (Treisman, 1982; see also Treisman & Gormican, 1988).

Another example comes from Baylis and Driver (1992), who used multiple versions of a target categorisation task to determine the effects of perceptually similar distractors to that of targets. Across eight experiments, grouping factors such as similarity (e.g., colour) and good continuation influenced the amount of interference that distractors elicited (with perceptually similar distractors eliciting more interference than nonsimilar distractors), indicating a strong influence of grouping principles on visual attention and visual tasks. Furthermore, Driver and Baylis (1989) reported that the grouping factor of common motion influences performance in a flanker task, with more interference elicited by distractors moving simultaneously with a target (but see Berry & Klein, 1993, for a failure to replicate). More recently, Woodman, Vecera, and Luck (2003) have demonstrated that perceptual grouping influences the storage of information in visual working memory. Specifically, individuals were better able to detect changes in a visual array at a location that was perceptually grouped with a cued location relative to when the change occurred at a location that was not perceptually grouped with, but equidistant from, the cued location. Collectively, the aforementioned research suggests that grouping factors strongly influence the allocation of visual attention (see also Kim & Cave, 2001; Prinzmetal & Banks, 1977; Treisman, 1982).

Given that there is evidence that (1) the attention system treats perceptually grouped objects in a similar fashion to objects, and (2) attending to one portion of an object causes the entire object to be attended to, then (3) attending to one distinct element of a perceptual group should cause all of the grouped elements to be attended to. In other words, does the pattern of results found with the Egly et al. (1994) paradigm extend to situations in which the object consists of several elements grouped together through Gestalt principles? This is the question addressed by the present study.

EXPERIMENT 1

To determine whether perceptual organisation influences attention allocation in a manner similar to that reported by Egly et al. with single objects, we used a task in which participants detected probe targets in a 4 × 4 matrix consisting of 12 circle and 4 square placeholders. Within the matrix, the square placeholders were always located adjacent to each other (in a vertical, horizontal, or diagonal arrangement) and therefore would be grouped together by a set of Gestalt principles (e.g., similarity, good contiguity). It has already been established that similarity and good continuity mediate distractor interference on categorisation tasks (Baylis & Driver, 1992) and working memory tasks (Woodman et al., 2003), suggesting that the squares in the matrix will very likely be grouped together. On each trial, a square placeholder at one of the four corners of the matrix is cued, followed by a probe target at any of the circle or square placeholders. If object-based effects extend to situations in which the object consists of a set of similar items grouped by Gestalt principles, then cueing one square should cause all squares to be attended to. The result of this would be that responses to targets presented in square placeholders should be detected faster than targets in circle placeholders (when targets that are equally distant from the cue are compared).

Method

Participants. Eight students from the University of Toronto subject pool participated individually, in a single 1 hour session. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Apparatus and procedure. The experiment was conducted on a 486 PC with VGA monitor in a quiet, dimly lit, room. Participants were seated 44 cm from the front of the computer monitor with their heads held steady by a chin and headrest.

At the beginning of each trial, a central fixation point (white, 0.5° in diameter, 75.3 cd/m^2) and one of six experimental displays were presented on the computer monitor (see Figure 1). Each experimental display consisted of a 4×4 configuration of 12 white outline circle placeholders and 4 white outline square placeholders (each subtending 1.0°, separated horizontally and vertically by 1.5°, 75.3 cd/m^2) with a black background (0.43 cd/m^2). The four adjacent squares appeared either vertically aligned (on the left or right sides of the matrix), horizontally aligned (on the top or bottom sides of the matrix), or diagonally aligned. Participants were instructed to remain fixated on the central point for the duration of the experiment and to not move their eyes. Following a period of 1000 ms, one of the corner squares was cued by enlarging its outline for a period of 100 ms. Participants were told to ignore the cue because it did not indicate the location of the upcoming target. Following a 50 ms delay after the offset of the cue, a target (a filled-in white dot, 0.9°) appeared inside one of the 16 placeholders on the screen. The target was equally likely to appear inside any of the 16 placeholders and remained on screen until participants made a detection response by pressing the spacebar. To reduce anticipatory responses, catch trials in which the target did not appear were also included. Incorrect

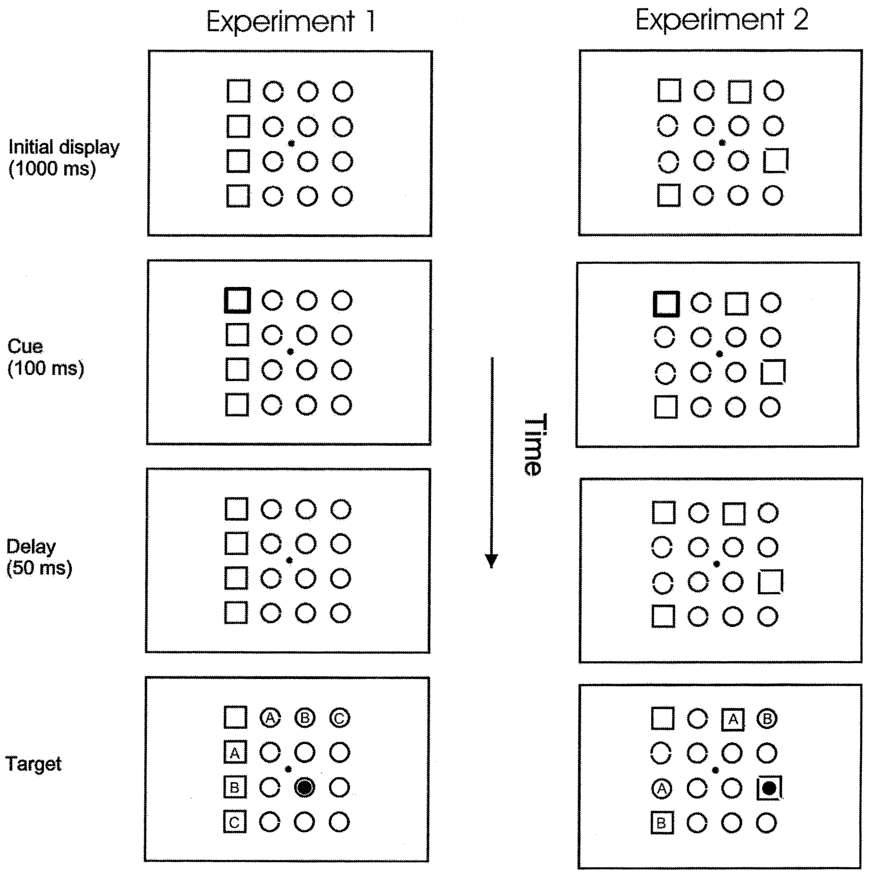

Figure 1. Trial sequence for Experiments 1 and 2. The critical comparisons are denoted in the fourth frame by the letters A, B, and C. Note that these letters did not actually appear on screen during the experiment.

responses (responses less than 100 ms and responses greater than 1000 ms, any response on a catch trial) were considered errors, and a short error tone was presented if any of these occurred. The next trial began 1000 ms after each response.

Design. The experiment consisted of 840 trials, with 706 test trials and 134 catch trials. This meant there were approximately 40 observations per condition per participant. The six experimental displays were equally likely to appear on any given trial. Short breaks were given after every 90 trials.

Results and discussion

Errors occurred on less than 1% of all trials and error trials were excluded from the analyses. Reaction times for targets as a function of placeholder shape and distance from the cue are presented in Table 1. Only trials on which the target appeared in a square or circle equally distant from the cue were used: The RTs for targets appearing in each position were collapsed across the vertical and horizontally grouped displays as there was no significant difference between RTs in these displays ($p > .3$).[1]

The mean RTs were analysed with a 2 (Shape: circle or square) $\times$ 3 (Distance from cue: 1, 2, or 3 positions) analysis of variance (ANOVA). There was a significant main effect of shape, $F(1, 7) = 6.48$, $MSE = 373.71$, $p < .04$, with faster RTs for targets in square objects than for targets in circle objects in every position. In addition, there was a significant main effect of distance from the cue, $F(2, 14) = 7.68$, $MSE = 658.38$, $p < .01$, with the longest RTs for targets

TABLE 1
Mean RTs (ms) and standard error (in brackets, below the RTs) for targets at all locations

	Experiment 1				*Experiment 2*			
Position from cue	*Cued shape 0*	*Uncued shape 1*	*Uncued shape 2*	*Uncued shape 3*	*Cued shape 0*	*Uncued shape 1*	*Uncued shape 2*	*Uncued shape 3*
0	*370* (14)	**360** (15)[a]	**351** (11)[b]	**395** (13)[c]	*396* (13)	357 (12)	**348** (15)[a]	**341** (13)[b]
1	**348** (11)[a]	352 (15)	356 (12)	368 (13)	344 (14)	386 (15)	349 (11)	348 (14)
2	**346** (13)[b]	350 (13)	363 (14)	371 (15)	**346** (14)[a]	347 (11)	347 (13)	368 (13)
3	**368** (12)[c]	376 (14)	368 (11)	392 (12)	**358** (12)[b]	359 (12)	352 (15)	391 (12)

The upper left cell of each table represents the RT at the cued location (the italicised number) while the RTs for the cued shape appear in the remaining cells of the first column and the equivalent comparisons for the uncued shape appear in the remaining cells of the first row (the bold numbers) for both Experiment 1 (grouped squares), Experiment 2 (ungrouped squares). The critical comparisons are denoted by the letters a, b, and c. Within each experiment, the two values represented by each letter were directly compared.

[1] Due to the spacing of the 4 $\times$ 4 matrices, placeholders appeared 1.5° from each other along the vertical/horizontal, but 2.12° from each other along the main diagonal. Thus, in trials on which squares were horizontally aligned, there were always circle placeholders at an equal distance from the cue along the vertical (and vice versa) and, therefore, within display comparisons between targets appearing in squares and targets appearing in circles were possible. Such was not the case on diagonal trials where squares occupied the main diagonal that was cued and no circle appeared at an equal distance from the cue as these squares. Because of this, diagonal grouping trials were only included so that targets could appear in any position in the matrix in either a square or circle, but these trials were excluded from all analyses. Nonetheless, the RTs for targets appearing at all positions can be seen in Table 1.

three positions from the cue and the shortest RTs when the target appeared two positions away from the cue (although the difference between RTs when the target appeared three positions away from the cue relative to one position away from the cue was not significant, $p = .23$). There was no interaction between shape and distance, $F(2, 14) < 1$. Thus, participants were significantly faster to respond to targets that appeared in squares that were grouped together relative to when the target appeared in a circle at equal distance.

Interestingly, participants in the present experiment were slow to detect targets appearing at the cued location. Normally, the opposite pattern of results is expected: faster RTs for targets appearing at a cued location. The slowed response times at the cued location are likely due to a forward masking effect whereby it was difficult for subjects to differentiate between the offset of the cue and the onset of the target due to the brief duration between cue and target, as well as perceptual similarities between the two (Gibson, 1996a, 1996b; see Breitmeyer, 1984, for a review). Indeed, several subjects spontaneously commented on this. The slowed RTs at the cued location appear to be a function of the basic paradigm as identical results are observed in Experiments 2 and 3. The possible influence of forward masking will be given further attention in Experiment 4.

EXPERIMENT 2

Although an object-based grouping effect was obtained in Experiment 1, another interpretation of the results is possible. It might have been that the faster RTs for targets in the square placeholders occurred because a square was always cued at the beginning of each trial. In other words, the faster RTs may not have been due to grouping but rather shape-based object priming. A further alternative explanation is that fewer squares than circles were used and, thus, squares comprised a unique subset which may have made them more likely to be attended.

To eliminate this possibility, the present experiment was conducted in which square placeholders never appeared in adjacent positions in the experimental displays. If the RT advantage for targets in squares in the first experiment was due to a grouping effect, then this advantage should not be found in the present experiment. If, however, the previous effect was due to squares being primed or squares comprising a unique subset, then the RT advantage for square placeholders should be found in the present experiment.

Method

Participants. Eight students from the University of Toronto subject pool participated individually, in a single 1 hour session. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Apparatus, procedure, and design. The apparatus, procedure, and design of Experiment 2 were the same as in Experiment 1, with the sole exception that squares were no longer grouped together in the 4 × 4 configurations. To do this, six experimental displays were created in which the squares never occurred in adjacent positions (see Figure 1 for an example of the new display type). As before, all the experimental displays contained squares in two of the corners.

Results and discussion

Errors occurred on less than 2.6% of trials and all errors were excluded from the analyses. Reaction times for targets as a function of object shape and distance from the cue are also presented in Table 1 (as in Experiment 1, trials on which square placeholders appeared on the diagonal were excluded from the analysis). Again, only trials on which the target appeared in a square or circle equally distant from the cue were used and reaction times for targets appearing in each position were again collapsed across experimental displays where appropriate.

The mean RTs were analysed with a 2 (Shape: circle or square) × 2 (Distance from cue: 2 or 3 locations) ANOVA (because squares were never located in adjacent locations, there is no 1 location from cue condition). There were no significant main effects or interactions, $F(1, 7) = 2.09$, $MSE = 363.29$, $p = .19$ for the shape/distance interaction, all other Fs < 1, indicating that the response time benefit for targets appearing in squares in Experiment 1 was due to the grouping together of squares and not object priming. Note that once again the slowest RTs are for targets at the cued locations.

EXPERIMENT 3

Though the results of Experiment 2 indicate that the response time benefit for items appearing in squares in Experiment 1 was not due to object priming, Experiment 3 was designed to be a more thorough test of this account. Thus, a number of changes were made to the basic design of Experiments 1 and 2. First, the number of items in the visual display was reduced from 16 to 9 so that either corner circles or corner squares could be cued at the beginning of each trial. To this end, the sample size was increased to make certain that a sufficient number of observations were collected at each possible target location. Second, the matrix now consisted of three squares, three triangles, and three circles to ensure that the advantage for targets appearing in squares was not attributable to the squares comprising a unique subset that might capture attention independent of perceptual grouping. Third, the cue and target types were altered in an attempt to eliminate the forward masking at the cued location observed in Experiments 1 and 2. Finally, we monitored eye movements in Experiment 3 to ensure that only attention was being captured by the peripheral cues.

Method

Participants. Fifteen students from the University of Toronto subject pool participated individually, in a single 1 hour session. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Apparatus and procedure. The experiment was conducted on a 486 PC with VGA monitor in a quiet, dimly lit, room. Participants were seated 44 cm from the front of the computer monitor with their heads held steady by a chin and headrest.

At the beginning of each trial, one of four experimental displays was presented on the computer monitor (see Figure 2). Each experimental display consisted of a 3 $\times$ 3 configuration of three white outline circle placeholders, three white outline square placeholders, and three white outline triangle placeholders (each subtending 2°, separated horizontally and vertically by 2°: 75.3 cd/m^2) on a black background (0.43 cd/m^2). The three adjacent squares appeared either vertically aligned (on the left or right sides of the matrix) or horizontally aligned (on the top or bottom sides of the matrix). The three adjacent triangles always appeared in the centre of the display (vertically when the squares were arranged vertically, horizontally when the squares were arranged horizontally), and the three adjacent circles always appeared on the opposite side of the squares in the display. Participants were instructed to remain fixated on the central triangle for the duration of the experiment and to not move their eyes. To ensure that eye movements did not occur, gaze was monitored with a closed circuit camera system. No eye movements were observed by the experimenter and, consequently, no data was omitted from the experiment.[2] Following a period of 1000 ms, one of the corner objects (square or circle) was cued by presenting a small filled-in white dot (0.9°) at the centre of the object for a period of 100 ms. Participants were told to ignore the cue because it did not indicate the location of the upcoming target. Following a 50 ms delay after the offset of the cue one of the nine placeholders on the screens filled in in white. The target was equally likely to appear inside any of the nine placeholders and remained onscreen until participants made a detection response by pressing the spacebar. To reduce anticipatory responses, catch trials in which the target did not appear were also included. Incorrect responses (responses less than 100 ms

[2] Participants were continuously monitored for eye movements by the experimenter. No eye movements were observed for any participants and consequently, no data was omitted from the study. It is important to note that the SOA between cue and target was so brief (50 ms) that an eye movement could not be made during that time. Moreover, we have performed a variety of simple detection tasks in our laboratory (both with eye monitoring and without) and have found no differences in performance across experiments. Participants are generally very good at remaining fixated during these tasks given that the stimuli subtend a relatively small portion of the field of view, are static, and have high contrast from the background.

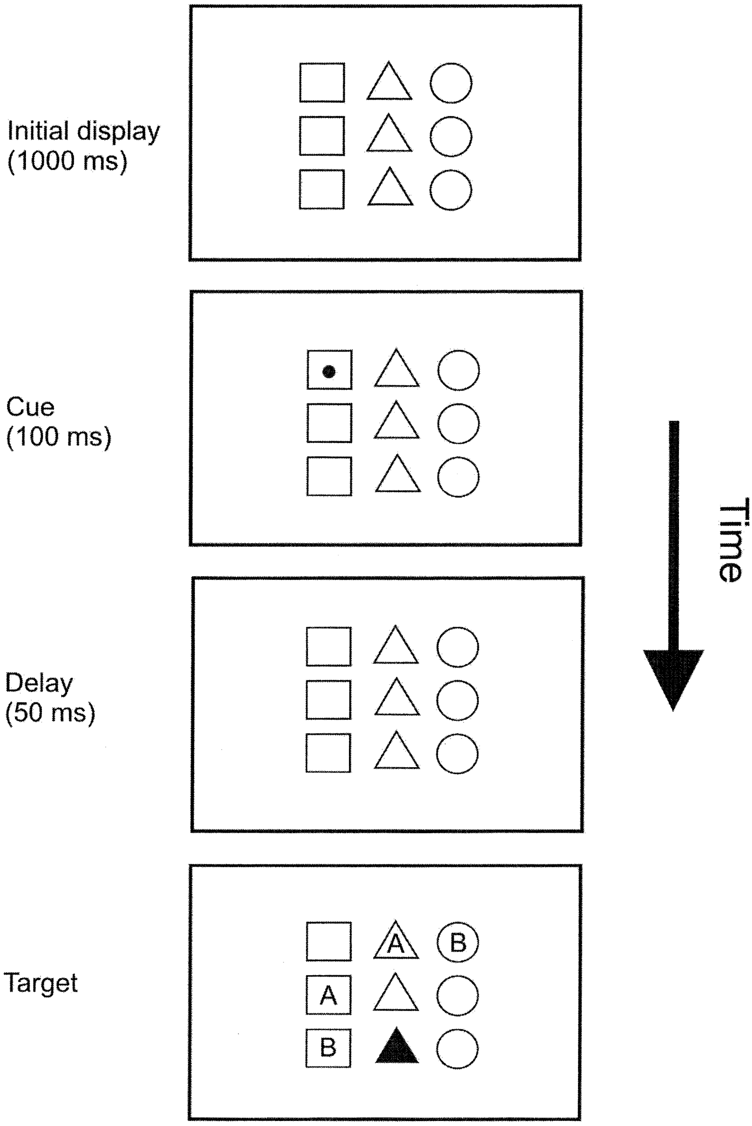

Figure 2. Trial sequence for Experiment 3. As in Figure 1, the critical comparisons are denoted by the letters A and B. Note that these letters did not actually appear on screen during the experiment.

and responses greater than 1000 ms, any response on a catch trial) were considered errors, and a short error tone was presented if any of these occurred. The next trial began 1000 ms after each response.

Design. The experiment consisted of 600 trials, with 480 test trials and 120 catch trials. This meant there were approximately 50 observations per condition per participant. The four experimental displays were equally likely to appear on any given trial. Short breaks were given after every 100 trials.

Results and discussion

Errors occurred on less than 2.1% of trials and all errors were excluded from the analyses. Reaction times and difference scores for targets as a function of object shape and distance from the cue are presented in Table 2. Again, only trials on which the target appeared in a square, triangle, or circle equally distant from the cue were used and reaction times for targets appearing in each position were again collapsed across experimental displays where appropriate.[3]

The mean RTs were analysed with a 2 (Shape: cued or uncued) $\times$ 2 (Distance from cue: 1 or 2 locations) ANOVA. Note that a cued shape could have been a square or a circle, whereas an uncued shape could have been a square,

TABLE 2
Mean RTs (ms) and standard error (in brackets, below the RTs) for targets at all locations

	Experiment 3			*Experiment 4*		
Position from cue	*Cued shape 0*	*Uncued shape 1*	*Uncued shape 2*	*Cued shape 0*	*Uncued shape 1*	*Uncued shape 2*
0	*394* (12)	**392** (14)[a]	**395** (13)[b]	*318* (15)	**298** (15)[a]	**293** (15)
1	**378** (13)[a]	387 (15)	381 (12)	**297** (14)[a]	287 (17)	289 (14)
2	**390** (12)[b]	391 (11)	393 (15)	**295** (15)[b]	281 (14)	287 (15)

The upper left of each table represents the RT at the cued location (the italicised number) while the RTs for the cued shape appear in the remaining cells of the first column and the equivalent comparisons for the uncued shape appear in the remaining cells of the first row (the bold numbers) for both Experiment 3 and Experiment 4. The critical comparisons are denoted by the letters a and b. Within each experiment, the two values represented by each letter were directly compared.

[3] As in Experiments 1 and 2, trials on which the target appeared in a location diagonal to the cue were not included in analyses for Experiments 3 and 4 given the difference in proximity in targets along the diagonal relative to targets appearing horizontal or vertical from the cue. Nonetheless, the RTs for targets appearing at all positions can be seen in Table 2.

circle, or triangle. There was a significant main effect of shape, $F(1, 14) = 14.93$, $MSE = 1530.15$, $p < .01$, with faster RTs for targets in the cued shapes (square/circle) objects than for targets in the uncued shapes (triangle/circle/square) objects in every position. This replicates the grouped object-based findings from Experiment 1. In addition, there was a significant main effect of distance from the cue, $F(1, 14) = 4.26$, $MSE = 215.48$, $p < .05$, with the longest RTs for targets two positions from the cue and the shortest RTs when the target appeared one position away from the cue. There was no interaction between shape and distance, $F(1, 14) = 3.27$, $MSE = 126.29$, $p > .10$.

As in Experiments 1 and 2, participants in the present experiment were slow to detect targets appearing at the cued location. Though we altered the cue and target types, participants still spontaneously commented that they had difficulty differentiating between the offset of the cue and the onset of the target.

EXPERIMENT 4

In Experiments 1 and 3 we observed a response time benefit for targets appearing in cued shapes relative to targets appearing in uncued shapes that were equidistant from the cue. This finding both replicates and extends the object-based effect initially observed by Egly et al. (1994a) to displays consisting of perceptually grouped objects. There was, however, one peculiar aspect of the results in all three experiments: The slowest detection times were always for targets appearing at the cued location. While this was likely attributable to forward masking from the cue given the short duration between cue and target (indeed, several participants commented spontaneously that the target at the cued location was very difficult to detect), we can not be certain that the cue captured attention given the lack of a cueing effect at the cued locations. The purpose of Experiment 4, therefore, was twofold. First, rather than looking for a cueing effect, we extended the SOA to 1000 ms to determine whether we observed inhibition of return (IOR) at the cued location. Inhibition of return refers to the finding that targets that appear at previously attended or cued locations are more slowly responded to than targets that appear at uncued locations when a relatively long temporal interval (typically 200 between 2000 ms) intervenes between the two peripheral events (e.g., Posner & Cohen, 1984; for a more recent review, see Klein, 2000). As Pratt, Hillis, and Gold (2001) note, because the time frame for IOR is beyond that of sensory masking effects, IOR is a better indicator of where attention *was* than attentional cueing effects may be for where attention *is*. If IOR were to be found at the cued locations in this experiment, it would suggest that the cues in our earlier experiments did indeed capture attention.

The second purpose of this experiment was to examine if inhibition spreads to perceptually grouped objects in a manner similar to contiguous objects. Both Jordan and Tipper (1999) and Reppa and Leek (2003) have demonstrated that

IOR spreads across a single surface of an object using a modified version of the Egly et al. (1994a) paradigm. Thus, there is reason to believe that similar object-based attention effects will be found with IOR and perceptually grouped objects.

Method

Participants. Fifteen students from the University of Toronto subject pool participated individually, in a single 1 hour session. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Apparatus and procedure. The apparatus and procedure were identical to Experiment 3 with the sole exception that the delay between cue and target was increased to 1000 ms. As in Experiment 3, gaze was monitored with a closed circuit camera system. No eye movements were observed by the experimenter and, consequently, no data was omitted from the experiment.

Design. The experiment consisted of 600 trials, with 480 test trials and 120 catch trials. This meant there were approximately 50 observations per condition per participant. The four experimental displays were equally likely to appear on any given trial. Short breaks were given after every 100 trials.

Results and discussion

Errors occurred on less than 1.8% of trials and all errors were excluded from the analyses. Reaction times and difference scores for targets as a function of object shape and distance from the cue are presented in Table 2. Again, only trials on which the target appeared in a square, triangle, or circle equally distant from the cue were used and reaction times for targets appearing in each position were again collapsed across experimental displays where appropriate.

The mean RTs were analysed with a 2 (Shape: cued or uncued) $\times$ 2 (Distance from cue: 1 or 2 locations) ANOVA. Note that a cued shape could have been a square or a circle, whereas an uncued shape could have been a square, circle, or triangle. There were no significant main effects or interactions, $F(1, 15) = 1.43$, $MSE = 136.57$, $p = .25$ for the main effect of distance, all other Fs < 1. To determine whether IOR was observed at the cued location, a one-way ANOVA was performed on the RTs at the aforementioned target locations. There was a main effect of target location, $F(4, 60) = 11.9$, $MSE = 143.75$, $p <$ .001, with the longest RTs occurring at the cued location. Paired sample t-tests confirmed that IOR occurred at the cued location relative to the other target locations (all ps < .001). There was, however, no evidence that IOR spread to the grouped objects.

GENERAL DISCUSSION

The present experiments demonstrate that independent elements that can be grouped into a perceptual object as a function of Gestalt principles elicit object-based effects similar to those first reported by Egly et al. (1994a). There had been some uncertainty regarding the degree to which the original Egly et al. results were specific to the objects and displays used (e.g., Avrahami, 1999; Watson & Kramer, 1999). Here, however, we extend the object-based effect to new displays in which the ‘‘object’’ is comprised of a set of distinct items that are grouped according to similarity. In Experiment 1, detection responses were faster for targets appearing in adjacent square placeholders relative to targets appearing in circle placeholders at an equal distance from the cue, a result comparable with the object-based attentional advantage observed by numerous researchers (e.g., Egly et al., 1994a; Moore et al., 1998; Pratt & Sekuler, 2001). The RT advantage for square placeholders, however, disappeared when the squares could not be grouped together in Experiment 2, indicating that the faster responses were not due to object priming or the smaller subset of squares relative to circles. Experiment 3 provided converging evidence for object-based attention effects with perceptually grouped objects as an RT advantage was again found for grouped objects, despite both squares and circles being cued and squares no longer forming a unique subset of the visual display. Using a long SOA, Experiment 4 provided evidence that, despite the lack of facilitation at the cued locations in the previous experiments, the brief onset cues do capture attention. Unlike the facilitatory attention effects examined in Experiments 1–3, the results from Experiment 4 indicate that IOR does not spread across grouped objects.

The present results have strong links to the perceptual grouping literature, as well as the object-based attentional literature. Though the influence of Gestalt principles in visual tasks had been previously established in earlier research (e.g., Baylis & Driver, 1992), the present results found that the RT advantage for targets appearing in grouped squares relative to circles at an equal distance from the cue mirrors what has been observed in numerous studies of object-based attention that have used perceptually contiguous objects (e.g., Egly et al., 1994a; Moore et al., 1998). Although it has been posited that cueing a portion of an object causes the entire object to be attended, the present results extend this notion to suggest that cueing an object can cause a set of grouped objects to be attended. The boundary conditions for this effect are strict, however, as no object-based effect was observed in Experiment 2 despite the fact that squares could still be grouped as a unique noncontiguous subset on the basis of similarity. Furthermore, IOR was not observed to grouped objects in Experiment 4 despite early facilitation at grouped locations. Thus, while some researchers have reported that IOR spreads across the surface of a single object (e.g., Jordan & Tipper, 1999; Reppa & Leek, 2003), the present results provide preliminary evidence that IOR does not spread across multiple objects that can be grouped according to Gestalt principles. This is not surprising given that both Danziger and Kingstone (1999) and Posner and Cohen (1984) have posited that facilitation and inhibition are distinct effects that may be attributable to different mechanisms. Thus, early facilitation does not always lead to inhibition, nor is the presence of inhibition dependent on early facilitation.

The present results are also consistent with the notion that visual attention and perceptual grouping share common mechanisms, a notion that is gaining credence given a number of recent neurophysiological and psychophysical findings (for a review, see Grossberg & Raizada, 2000). Importantly, attention and grouping seem to interact in a reciprocal manner (e.g., Carrasco & Chang, 1995; Prinzmetal & Keysar, 1989) which provides a straightforward explanation as to why object-based effects extend to distinct objects that can be perceptually grouped as a function of Gestalt principles. Thus, certain perceptual effects, such as grouping, will obligatorily affect the attentional system and vice versa. This can be seen in the work of Raizada and Grossberg (2001; see also Grossberg & Raizada, 2000), who have put forth a unified model of perceptual grouping, attention, and orientation contrast in which the laminar circuits of the visual cortical areas V1 and V2 play a central role in all of these processes. The present results provide behavioural data consistent with their notion that attention and grouping are controlled by similar, if not identical, neurophysical substrates.

In summary, the present experiments demonstrate that independent objects that can be grouped as a function of Gestalt principles elicit object-based effects similar to those first reported by Egly et al. (1994a). In both Experiments 1 and 3, an RT advantage was observed for targets appearing in objects that could be perceptually grouped with a cued object relative to equidistant objects that could not be perceptually grouped with the cued object. Experiment 4, however, demonstrated that IOR does not spread through grouped objects despite some evidence that IOR can spread through the surface of a single object (e.g., Jordan & Tipper, 1999; Reppa & Leek, 2003). Taken together with other research, the present findings suggest that object-based attention extends to grouped objects, and further supports the possibility that attention and perceptual grouping are driven by common mechanisms.

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