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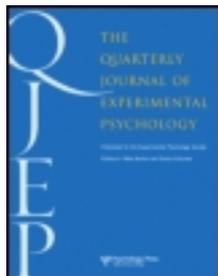
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### Object-based processes in the planning of goal-directed hand movements

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## Object-based processes in the planning of goal-directed hand movements

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Theories in motor control suggest that the parameters specified during the planning of goal-directed hand movements to a visual target are defined in spatial parameters like direction and amplitude. Recent findings in the visual attention literature, however, argue widely for early object-based selection processes. The present experiments were designed to examine the contributions of object-based and space-based selection processes to the preparation time of goal-directed pointing movements. Therefore, a cue was presented at a specific location. The question addressed was whether the initiation of responses to uncued target stimuli could benefit from being either within the same object (object based) or presented at the same direction (space based). Experiment 1 replicated earlier findings of object-based benefits for non-goal-directed responses. Experiment 2 confirmed earlier findings of space-based benefits for goal-directed hand pointing movements. In Experiments 3 and 4, space-based and object-based manipulations were combined while requiring goal-directed hand pointing movements. The results clearly favour the notion that the selection processes for goal-directed pointing movements are primarily object based. Implications for theories on selective attention and action planning are discussed.

When interacting with objects in our visual environment, an actor often needs to select one object out of many other possible objects. To accomplish this, selective attentional processes are thought to precede overt responses like saccadic eye movements (e.g., Godijn & Pratt, 2002) and goal-directed hand movements (e.g., Tipper, Lortie, & Baylis, 1992). Several decades of research have provided a broad knowledge about the operations and neural mechanisms of selective attention on the one hand and about the processes necessary to programme

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goal-directed movements to interact with the selected object on the other hand. Nevertheless, many issues are still under debate both within these two typically separated research fields and in the research work that examines the integration and coordination of selective attention and goal-directed movements.

Cogent to the present study, a broad discussion has been going on about the specific operations that are used in the allocation of visual attention. So-called space-based models suggest that visual attention is directed to particular locations in a purely spatial representation of the visual field. Previously, the analogue of a spotlight or zoom lens has often been suggested (e.g., Eriksen & Yeh, 1985; Posner, 1980), although more recently an attentional gradient model has been suggested as well (e.g., Laberge & Brown, 1989). The basic notion common to these studies is that attention is allocated to the spatial location of the cue. If the subsequent target stimulus then appears at the attended location (i.e., the cue was valid), responses can be made very quickly. If, however, the target stimulus appears at an unattended location (i.e., the cue was invalid), responses are slower because attention must be reallocated from the cued location to the target location.

In contrast, so-called object-based models suggest that attention is directed not to spatial locations but to objects in the visual field.<sup>1</sup> A good example of evidence for object-based attention comes from Duncan's (1984) study. In this study, participants had to judge specific features of an outline box with another line superimposed across it. The box was short or tall and had a gap in its left or right side, whereas the line was dashed or dotted and had a positive or negative slope. When participants had to judge two of these four features, accuracy was higher when the features occurred on the same object (e.g., short and left) than when the features occurred on different objects (e.g., short and dashed). Because all of the features overlapped (i.e., no difference in spatial location), Duncan suggested that attention is allocated to individual objects and that it takes time to switch attention from one object to another. A wide variety of studies have since confirmed the importance of objects in the allocation of visual attention (e.g., Baylis & Driver, 1992; Goldsmith, 1998; Hillstrom & Yantis, 1994; Tipper et al., 1997).

Although space-based and object-based models of attention are sometimes viewed as mutually exclusive, there is evidence that both types of attention allocation can conjointly influence behaviour. The effect of both space-based and object-based attention was elegantly shown by Egly and colleagues (Egly, Driver, & Rafal, 1994b; Egly, Rafal, Driver, & Starrveveld, 1994a; but see also Lamy & Egeth, 2002). Using a display consisting of two identical rectangles arranged in parallel, they cued one end of one rectangle and then presented a simple detection target. The target stimulus was most likely to occur at the cued end of the cued rectangle. However, on some trials, the target could occur at the uncued end of the cued rectangle or at the adjacent uncued end of the uncued rectangle. As a result, the distance between the uncued end of the cued rectangle and the uncued end of the uncued rectangle was equal. Two important effects were found. First, responses to targets at the uncued end of the cued rectangle were slower than those at the cued end, indicating that the distance between

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<sup>1</sup>In the present experiments space-based and object-based effects are contrasted. However, it would not be correct to treat them as mutually exclusive. A location, for instance, is always cued by an object, and an object is always presented somewhere in space.

cues and targets influences detection latencies (i.e., space-based attention). Second, responses to targets at the uncued end of the cued rectangle were faster than responses to targets on the uncued end of the uncued rectangle, even though both ends were the same distance from the cue. Egly et al. (1994a, 1994b) interpreted this as an object-based attention effect; orienting attention to one end of an object causes the entire object to be attended to and reduces detection latencies for targets anywhere on the cued object. The presence of both space-based and object-based effects has been replicated in several variations of this paradigm (e.g., Abrams & Law, 2000; Kramer & Weber, 1999; Moore, Yantis, & Vaughan, 1998; Pratt & Sekuler, 2001).

As already stated in the beginning of this introduction, we typically shift our covert attention to objects or locations in our environment during the preparation of overt responses like saccadic eye movements and goal-directed hand movements to the selected object or position. Many investigations have been undertaken to shed some light on the operations and neural mechanisms that precede overt responses like saccadic eye movements and goal-directed hand movements. Interestingly, a strong consensus seems to exist in the literature regarding the planning processes that take place in the brain before executing a saccade or a goal-directed hand movement to a specific location. For almost 20 years now, the findings of Georgopoulos and others (e.g., Alexander & Crutcher, 1990; Georgopoulos, 1986, 2000; Georgopoulos, Kalaska, Caminiti, & Massey, 1982) have provided convincing evidence that direction is the key control parameter in the specification of a reaching movement. The basic finding is that the activity of single cells in the motor cortex are broadly tuned with respect to the direction of reaching, so that the discharge rate is highest with movements in a preferred direction and decreases progressively with movements made in directions more and more away from the preferred one. Therefore, Georgopoulos concludes that the neural command for the direction of reaching can be regarded as an ensemble of cell vectors, with each vector pointing in the cell's preferred direction and having a length proportional to the change in cell activity. Moreover, when a mental transformation is required for the generation of a reaching movement in another direction from a reference direction, the population vector abruptly shifts from the originally activated vector into the required vector (e.g., Pellizzer, Sargent, & Georgopoulos, 1995). An example of this comes from a series of experiments by Ashe and Georgopoulos (1994) in which the ongoing impulse activity of 290 cells in the motor cortex and 207 cells in area 5 was analysed. For most cells statistically significant relations were observed to both target direction and position, velocity, and acceleration, but most prominent were the relations to target direction and least prominent those to acceleration.

There is also evidence at the human behavioural level that the specification of the new desired position of gaze and hand relative to the current position needs to be in spatial coordinates like direction and amplitude. For instance, Rosenbaum (1980) found evidence that specification times for arm selection and for direction and extent of the chosen arm movement were specified serially, but not in an invariant order. Abrams and Jonides (1988) also found evidence that direction and amplitude for an upcoming saccade were calculated separately. In addition, some authors have suggested a close link between the processes underlying covert movements of attention and overt movements of the eyes (e.g., Posner, 1980; Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Shepherd, Findlay, & Hockey, 1986), suggesting that covert attention is also directed in terms of direction and amplitude.

In sum, there is converging evidence that from an early moment in the response planning, up till response initiation, the production of goal-directed responses is planned in parameters

such as direction and amplitude. In contrast, the evidence for the parameters concerned with attentional selection processes has been demonstrated to contain a nonspatial component of visual attention that is involved in shifting attention between objects. The purpose of the present study is to investigate the possibility that such object-based selection processes might influence the planning of goal-directed responses as well.

## Rationale and overview of the present study

The present experiments were designed to examine the contributions of object-based and space-based attentional cueing effects on the preparation time of goal-directed pointing movements. The basic paradigm of Egly et al. (1994a, 1994b) was adapted to work with goal-directed reaching responses. The basic premise used in these experiments is that the appearance of a cue, which indicates the most likely target location, will initiate the planning of a response (including the specification of such parameters as direction and amplitude) to that location. If space-based attention effects play a major role in the planning of goal-directed reaching responses, then it should be easier to initiate movements that require fewer changes in parameters. In other words, it should be faster to initiate movements to uncued locations that share more parameters with the cued location than to locations that share fewer parameters. However, if object-based attention effects play a major role in the planning of such movements—that is, if attention attracted by the cue is directed to objects in the visual field rather than to spatial locations—then it should be easier to adjust the planning of the upcoming response for a target stimulus in the same object than for a target stimulus that appears in another object.

To test these predictions, a series of four experiments were conducted. In Experiment 1, we attempted to replicate the original findings of Egly et al. (1994a, 1994b) of space-based and object-based attentional effects with non-goal-directed responses (detection key presses). That is, simple detection (i.e., nonspatial) hand responses should be fastest for targets at the cued location (space based), and faster responses for target stimuli at the uncued location within the same object are expected than at the uncued location of another object (object based). The results indeed showed the typical space-based and object-based advantages. Experiment 2 investigated space-based attentional effects for the initiation of goal-directed reaching responses in order to provide a baseline of performance with which to compare potential object-based attentional effects from the later experiments. In this experiment, targets occurred at uncued locations that did or did not require a change in direction relative to the hand starting position from the planned response to the cued location. The results showed space-based advantages for goal-directed pointing responses, with shorter reaction times (RTs) to uncued locations that did not require a change in direction. Experiments 3 and 4 used the same cue and uncued locations as those in the previous experiments, but now rectangular objects were placed in the display. In Experiment 3, two rectangles were placed in such a way that responses to the uncued location that required a direction change terminated in the same object as the cued location, while responses to the uncued location that did not require a direction change terminated at a location that was not bounded by an object. In this case, a large object-based attention effect was found, as RTs were now faster to uncued locations in the cued object, even though a change in direction was needed. Experiment 4 used the same basic display as that in Experiment 3 except that the two uncued locations both occurred within objects, but only one in the object that had been cued. Following the method from the previous

experiment, the uncued location in the cued object required a change in the planned direction while the uncued location in the uncued object did not require any change to the planned direction parameter. The results extended the findings from Experiment 3, as RTs were still faster to uncued locations in the same object as the cue, even though a change in direction was needed, confirming the importance of object-based attention effects in guided reaching responses.

## EXPERIMENT 1

The purpose of Experiment 1 was to replicate the original finding of Egly et al. (1994a, 1994b) with our apparatus. Whereas the typical version of the Egly et al. paradigm uses a computer monitor for displaying stimuli and keyboard for collecting responses, our stimuli were presented on a light-emitting diode (LED) board, and participants were required to perform finger-lifting responses. In addition to the typical Egly et al. display (2-object condition; two parallel rectangles with two LEDs in each object), an additional display was used that consisted of four smaller rectangles (4-object condition; four squares each with a single LED). It is worth noting that in each condition, the LEDs were in exactly the same spatial location on the LED board. Thus, in the 2-object condition, any object-based attention advantage should facilitate responses to locations that are in the same (cued) object compared to locations at the same distance of the cue in another object. However, any potential object-based advantage should disappear in the 4-object condition, where the same location is positioned in another object (see also Pratt & Sekuler, 2001).

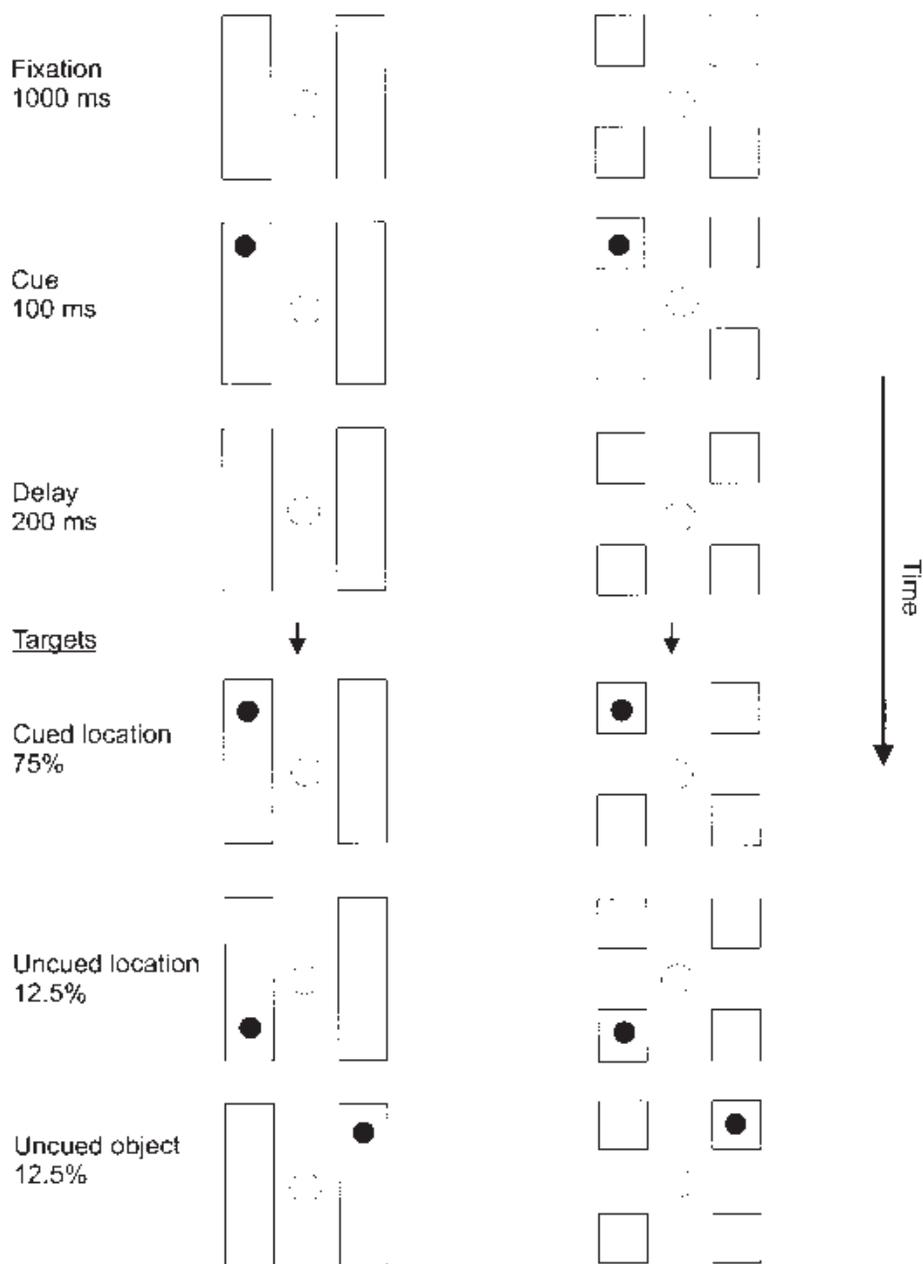
### Method

#### *Participants*

The participants were 8 paid undergraduates. All participants in all experiments were right-handed and used their dominant right hand for responding to the stimuli. They were naive about the purpose of the experiment. Each observer was tested individually in a separate session for the two conditions described above. Each session lasted about 45 minutes, and they were completed within a week of each other.

#### *Apparatus*

The stimuli were presented on a table that contained  $12 \times 8$  cylindrical holes (diameter was 5 mm); in each hole a two-collared LED was mounted (see Neggers & Bekkering, 2000, for a more detailed technical description). In the 2-object session, two paper rectangles ( $24 \times 4$  cm) were placed on top of some of the LEDs (rendering them invisible to the participants) in such a way that the distance between the top and the bottom LED within one rectangle was equivalent to the distance between the two top LEDs of the two rectangles—that is 20 cm. (see Figure 1). The rectangles consisted of a 1 by 22-cm frame, to create an object, while the rest of the paper was cut away to enable viewing of the LEDs below. Thus two LEDs were placed in the middle of the ends of each of the two rectangles. The fixation LED was positioned in the middle of the board. Over the paper rectangles a Plexiglas plate was mounted (thickness: 3 mm) to avoid manual contact with the rectangles. In the 4-object session, four paper squares ( $4 \times 4$  cm) were put at the same locations as the corner ends of the two-paper-rectangle condition. Also, these squares consisted of a 1 by 1-cm frame.



**Figure 1.** Example trials of Experiment 1 with uncued target stimuli that appeared in the same object as the cue (uncued-same-object) or in the other object (uncued-other-object). Also depicted on the right are the same example trials when four objects were presented on the LED board.

The position of the hand (index finger) was measured with a marker of the Optotrak infrared tracking system of Northern Digital™ with a tracking rate of 250 Hz, which was placed on the nail of the index finger. To calculate hand RT, the tangential velocity of the hand was calculated along the 3D trajectory of the index finger, and a velocity threshold of 0.05 m/s was used. A Butterworth (10-Hz cut-off) was used for filtering. This set-up of an LED “peg-board” with the Optotrak has been used successfully in the past to record movements to targets spread across a large surface area (e.g., Neggers & Bekkering, 2000, 2001).

### *Procedure*

Each trial began by lightening the fixation LED that was presented during the whole trial. After 1,000 ms one of the four LEDs in one of the corners of the two rectangles was lit for 100 ms. Then, 200 ms after the cue had disappeared, the target was lit. The target stimulus appeared at the cued location on 75% of the trials (cued location), at the uncued location of the same object on 12.5% of the trials (uncued–same-object), and at the equidistant uncued location of another object on 12.5% of the trials (uncued–other-object). As with Egly et al. (1994a, 1994b), this was done to ensure that the participants allocated attention to the cued location and that the target stimuli at the two possible uncued locations were equally likely and equally distant from the cued location. The target stimulus remained visible for another 1,500 ms, and then the trial was terminated, and also the fixation LED was turned off. After a 500-ms intertrial interval the next trial started.

The participants’ task was to lift the finger of the dominant right hand as rapidly as possible whenever a target was detected at any of the four rectangle ends and to withhold responses on the occasional catch trials with no targets. Participants were asked to position the hand just below the fixation LED in such a way that no LEDs were occluded. The participants were told that response latencies would be recorded but that they should minimize the number of errors on the catch trials. Also, participants were instructed to position the hand in such a way that all possible target positions were visible. Participants were strongly cautioned to maintain fixation throughout each trial. The experimenter monitored eye position visually during the practice phase.

The computer randomized the order of trials for each participant. There were eight blocks of 96 trials each, and a short rest period was offered between them. Before the experimental trials, a block of 20 practice trials was given. The experimenter explained the task while practice trials were being displayed and repeated the test block if eye movements were observed.

### *Design*

Half of the participants started with the 4-object condition followed by the 2-object condition, while this was counterbalanced for the other half of the participants. Each participant was given 640 target-present trials consisting of 480 cued trials (2 number of objects  $\times$  4 cue locations  $\times$  60 repetitions) and 160 uncued trials. For each of the two types of uncued trial, there were 10 repetitions for each of the eight cues (2 number of objects  $\times$  4 target locations). There were also 128 catch trials (16 repetitions of each of the eight cues).

## Results and discussion

*Kinematics.* We analysed the displacement of the IRED positioned on the index finger in detail on several kinematic variables (movement time, MT, or peak velocity) and spatial dependent variables (deviations in the curve or variable end position error) of the hand movements. However, we were not able to find systematic differences for movements to the same

TABLE 1  
Movement times and variable end-point errors for  
Experiment 1

| Condition       | MT <sup>a</sup> |      | Variable error <sup>b</sup> |      |
|-----------------|-----------------|------|-----------------------------|------|
|                 | M               | SE   | M                           | SE   |
| Cued 2-object   | 416             | 14.6 | 26.1                        | 0.1  |
| Uncued 2-object | 410             | 17.3 | 26.2                        | 0.2  |
| Cued 4-object   | 419             | 21.4 | 25.8                        | 0.27 |
| Uncued 4-object | 419             | 18.9 | 26.1                        | 0.22 |

<sup>a</sup> Movement time, in ms. <sup>b</sup> Variable end-point error, in mm.

position that were located in an object or not. In Table 1, the mean data and standard errors for MT (in ms) and variable errors (in mm) are reported.

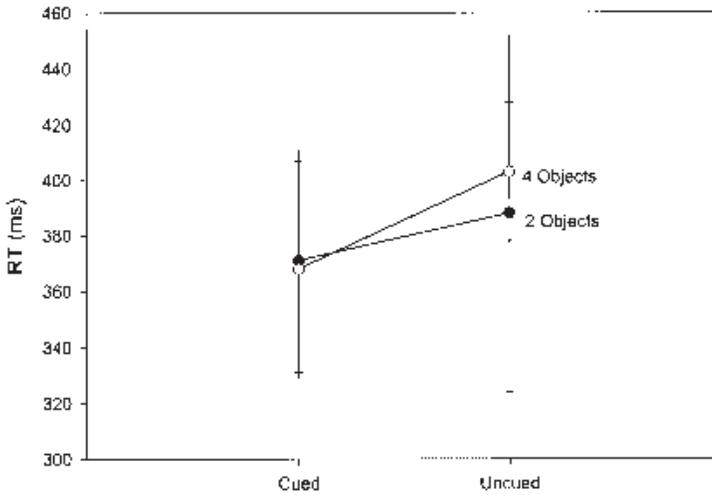
*Reaction times.* RTs of less than 150 ms were excluded as anticipations, as were false-alarm responses. To increase the power of the analysis, for each condition, the data for all four possible positions were combined. The mean hit rate on target present was 98.7%. A within-subjects one-way analysis of variance (ANOVA) on the errors (cued location, uncued-same-object, and uncued-other-object) showed no significant difference  $F(2, 7) < 1$ .

The mean RTs from the correct responses are shown in Figure 2 and were first analysed in a two-way within subjects ANOVA using cueing (cued or uncued) and display type (2-object or 4-object) as factors.<sup>2</sup> This was to determine whether, regardless of the type of display, targets at cued locations were detected faster than targets at any of the uncued locations. There was a significant main effect of cueing,  $F(1, 7) = 20.59, p < .003$ , with mean latencies of 369 and 395 ms for cued and uncued trials, respectively. This indicates that the expected attentional cueing effect was present. There were no other significant sources of variance.

Having established an overall cueing effect, we subsequently conducted separate two-way within-subjects ANOVAs for the uncued trials with display type (2-object or 4-object) and uncued trial (location or object) as factors. This was to specifically examine whether there was an object-based difference in the two uncued locations in both display conditions. No significant main effects were observed, but the critical interaction between number of objects and uncued trials was significant,  $F(1, 7) = 7.92, p < .03$ . This finding indicates that responses to uncued locations (366 ms) had shorter RTs than responses to uncued objects (399 ms) in the 2-object condition. However, in the 4-object condition such an effect was not found, although the responses were made to exactly the same spatial locations (402 ms for uncued location and 403 ms for uncued object); see also Figure 3.

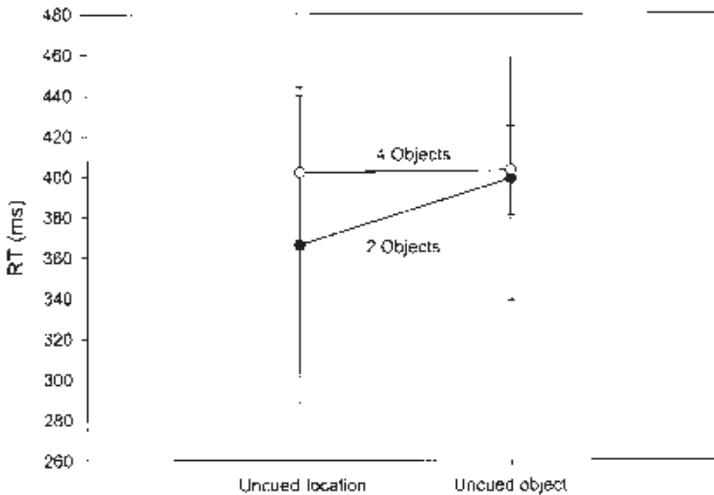
The RT advantage for responses to targets at uncued locations within the same object over responses to targets within another object replicates the findings of Egly et al. (1994a, 1994b) and provides further support for object-based theories of attention. Moreover, the

<sup>2</sup>Although we did measure kinematics of all movements in all experiments, we only report the MTs in Experiment 4, where responses were made to exactly the same location. However, since we were not able to find significant differences of theoretical interest here (nor in the other experiments), the article concentrates on the object-based and spatial-based RT effects.



**Figure 2.** Mean reaction time data for valid and invalid cued target stimuli in Experiment 1. The error bars reflect the standard error in both directions of the mean. Cue validity effects were found in both the 2- and 4-object condition.

fact that the object-based effect as found in the 2-object condition disappeared in the 4-object condition (although the locations are identical) provides additional support to the idea that indeed the presence of the objects causes the effect. An alternative explanation for the object-based effect—that is, a hemisphere advantage in the case in which the target stimulus appears at the same side of fixation—is rendered unlikely. That is, the appearance of



**Figure 3.** Mean reaction time data for responses to uncued locations that were presented at the same or the other side as the cue in Experiment 1. In the 2-object condition, responses to target stimuli at uncued locations that were presented at the same side (and thus in the same object) were faster than responses to the other side. No such an effect was found in the 4-object condition (where target stimuli thus were presented in another object).

targets at uncued locations at the same side of the fixation point as the cue is not enough to get shorter RTs. Instead, the target stimuli need to appear in the same object as the cue to facilitate RTs.

## EXPERIMENT 2

The purpose of Experiment 2 was to investigate the assumption that direction is the key control parameter in the specification of a reaching movement and thus that attentional processes underlying goal-directed hand movements are spatial based (e.g., direction and amplitude). To do so, exactly the same four cue positions as those in Experiment 1 were used. However, on trials in which reaching movements had to be made to uncued locations, the target stimuli were now presented either at the same direction (requiring no change in direction from a movement planned to the cue location from the fixation position) or at another direction (requiring a change in direction) (see Figure 4). It is important to note that in this experiment, the objects were removed from the LED board in order to provide a pure spatial-based pointing performance here that can be compared to potential object-based attentional effects in the next experiments.<sup>3</sup> If direction is indeed an important parameter for the preparation of goal-directed movements, RTs on the uncued location trials at the same direction should be faster than response latencies on the uncued trials at another direction.

### Method

#### *Participants*

The participants were 10 paid undergraduates. All participants in all experiments were right-handed and used their dominant right hand for responding to the stimuli. They were naive about the purpose of the experiment, and none had participated in the previous experiment. Each observer was tested individually in a separate session for the two conditions described above. Each session lasted about 45 minutes, and they were completed within a week of each other.

#### *Methods, apparatus, and design*

These were identical to those of Experiment 1 except for the following changes. First, no objects appeared on the LED board. Second, the uncued targets now appeared either in the same direction as the cue (7.07 cm beyond the cue location but along the same line from the start to the cue location), or in another direction (7.07 cm in the opposite direction, mirrored horizontally; see Figure 4). The same number of trials was used (768), and since the factor of number of objects was eliminated, there were twice as many cued and uncued (uncued–same–direction and uncued–other–direction) trials as in the previous experiment. Finally, the responses in this experiment were goal-directed reaching responses to the location of the target stimulus. Subjects were instructed to point to the target stimulus as quickly as possible. Also, they were asked to keep the finger in the original, straight orientation when moving. As a

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<sup>3</sup>A potential problem of this set-up is that the uncued target stimuli in the other direction were closer to fixation than the uncued target stimuli in the same direction. Thus, if a directional cue would shorten the RT latency of a goal-directed pointing movement compared to a cue with another angle, this would be the case in spite of a higher eccentricity. However, such an eccentricity effect would tend to be very small in magnitude (e.g., Bennett & Pratt, 2001).

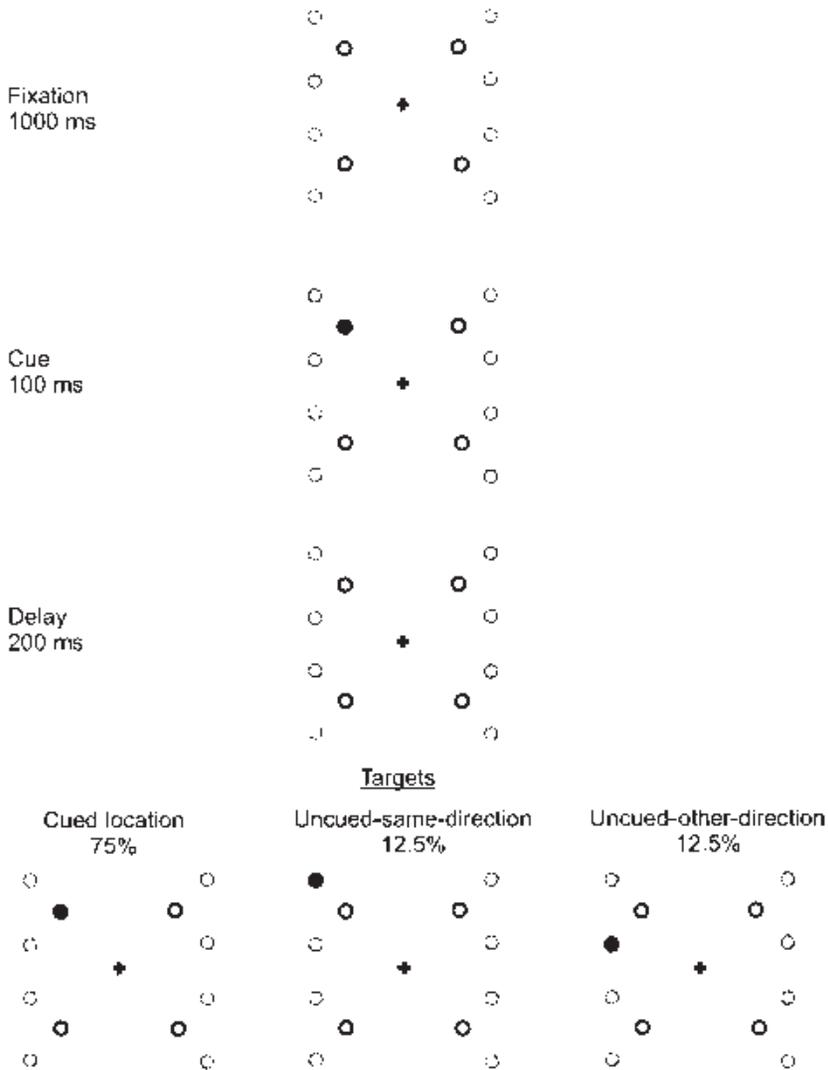


Figure 4. Example trials of Experiment 2 with target stimuli at the cued location (left lower panel), or at uncued locations but at the same direction as the cue (middle lower panel), or with another direction (right lower panel).

consequence, the vector evoked by the cue and the target stimuli that did not require a change of direction were about the same.

## Results and discussion

As before, RTs of less than 150 ms were excluded as anticipations, as were false-alarm responses. In addition, pointing movements that ended at the wrong end-point were excluded. To increase the power of the analysis, for each condition, the data for all four possible positions were combined. The mean hit rate on target present was 88.9%. A within-

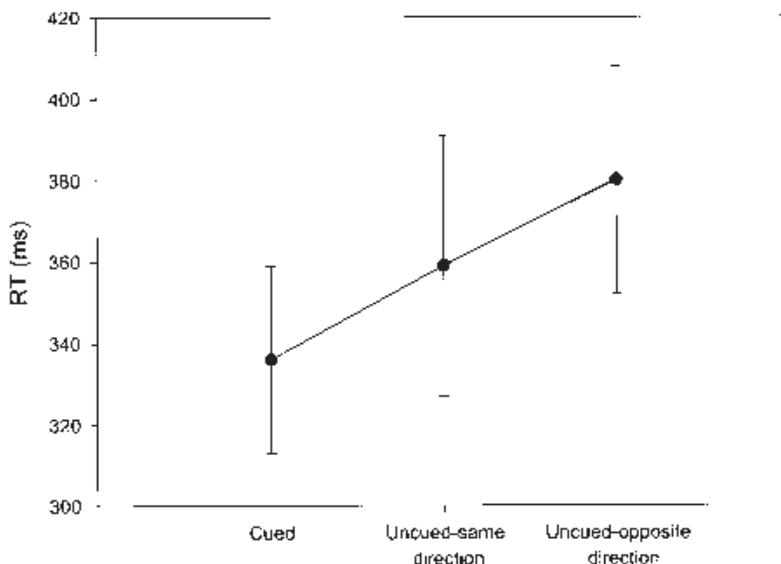


Figure 5. Mean reaction time data for Experiment 2. The error bars reflect the standard error in both directions of the mean. Responses to valid trials were fastest, followed by responses to invalidly cued locations at the same direction. Longest RTs were found for responses to invalidly cued locations with another direction.

subjects one-way ANOVA on the factor cue (cued, uncued–same-direction, and uncued–other-direction) showed no significant difference,  $F(2, 9) = 1.36, p > .3$ , for these errors.

Mean RTs from the correct trials are shown in Figure 5 and were analysed in a within-subjects one-way ANOVA on the factor cue (cued, uncued–same-direction, and uncued–other-direction). A significant main effect was found,  $F(2, 18) = 48.03, p < .001$ , and post hoc comparison adjusted for multiple comparison with the least significant difference method (LSD) showed that responses to cued targets (336 ms) were faster than responses to target stimuli at uncued locations at the same direction (359 ms) and that these were faster than responses to target stimuli at uncued locations at another direction (379 ms; all  $p$ s  $< .01$ ).

The RT advantage for responses to target stimuli on uncued locations at the same direction regarding the fixation position over responses to target stimuli on uncued locations at another direction indicates the presence of space-based effects for goal-directed movements in the absence of objects. Thus, consistent with previous work, the present study shows that RTs are faster when fewer spatially defined parameters have to be programmed (e.g., Abrams & Jonides, 1988; Rosenbaum, 1980).

### EXPERIMENT 3

The purpose of Experiment 3 was to combine the object-based effects of Experiment 1 with the space-based effects of Experiment 2 in a goal-directed movement task. Two objects were placed around these positions in such a manner that the “uncued–other-direction” target location of Experiment 2 was now within the same object as the cue location, while the “uncued–same-direction” target location was not positioned in any object. If direction is the critical

parameter for the selection of goal-directed responses, then faster RTs should be found for uncued targets at the same direction. However, if the object-based effect is the critical parameter for the selection of goal-directed responses, then faster RTs should be found for the uncued targets within the same object (even though movements to such targets require a change in direction).

## Methods

### *Participants*

The participants were 11 paid undergraduates. All participants in all experiments were right-handed and used their dominant right hand for responding to the stimuli. They were naive about the purpose of the experiment, and none participated in the previous experiment. Each observer was tested individually in a separate session for the two conditions described above. Each session lasted about 45 minutes, and they were completed within a week of each other.

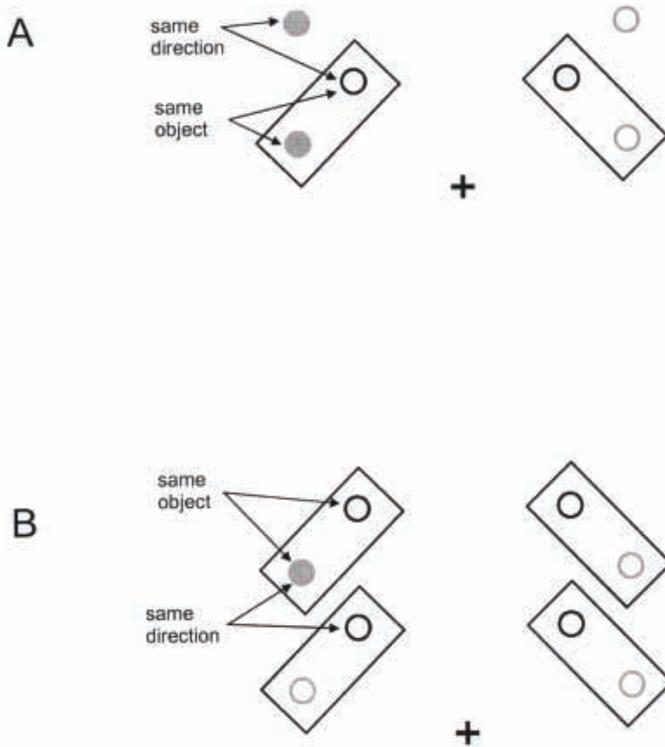
### *Methods, apparatus, and design*

These were identical to those of Experiment 2 except that now two objects were placed on the LED board, and only the upper two cue locations (and associated uncued locations) were used. We used only the two upper cued positions of Experiment 2 to avoid the otherwise necessary instructions about how to position the hand below the fixation point to avoid masking of the stimuli by the hand in the lower visual field. The objects were located such that each rectangle contained the cue location and the uncued–other-direction target, but not the uncued–same-direction target (see Figure 6A).

## Results and discussion

RTs of less than 150 ms were excluded, as were false alarms and pointing movements that ended at the wrong end-point. As before, the data for all four possible positions were combined for each condition. The mean hit rate on target present was 92.8%. A within-subjects one-way ANOVA on the factor cue (cued, uncued–same-object, and uncued–same-direction) showed no significant effect,  $F(2, 20) < 1$ , for the errors. Mean RTs from the correct trials are shown in Figure 7 and were analysed in a within-subjects one-way ANOVA on the factor cue (cued, uncued–same-object, and uncued–same-direction). A significant mean effect was found,  $F(2, 20) = 33.11, p < .001$ , with mean latencies of 338, 372, and 413, respectively. A LSD corrected post hoc test indicated that all three conditions were significantly different from each other, all  $ps < .002$ .

The RT advantage for goal-directed responses to uncued locations within the cued objects over responses to uncued locations in the planned direction, but not within the cued objects, is evidence that the selection of goal-directed responses is modified by the presence of objects. In other words, cueing one part of an object benefits the selection of goal-directed responses to other parts of the same objects. Moreover, the object-based advantage is greater than the space-based advantage of not changing the direction parameter found in the previous experiment. However, one possible limitation of the present findings is the fact that responses to the targets at uncued locations but in the same direction as the cue were not within any object at all. That is, the original finding of Egly et al. (1994a, 1994b) compared response latencies to uncued targets that were either in the same object or in another object. In the situation of



**Figure 6.** A. Example trials of Experiment 3 with target stimuli (depicted in grey) that appeared at uncued locations, either in the same direction as the cue or in another direction but within the object. B. Example trials of Experiment 4 in which the cue appeared either in the upper or the lower of the two rectangles. As a result, target stimuli (depicted in grey) at uncued locations appeared at exactly the same location. However, if the invalid cue was presented in the lower rectangle, the stimulus appeared in the same direction but within another object, whereas if the invalid cue was presented in the upper rectangle, the stimulus appeared in the same object but in another direction.

Experiment 3, it might well be that the RT advantage was due to the fact that the target stimulus appeared in an object and not per se to the fact that it was in the cued object. In other words, it may be that responses are easier to plan when targets appear in objects rather than in “empty” spatial locations. Indeed, there is evidence that the attentional system is especially sensitive to objects (e.g., Hillstrom & Yantis, 1994) and may assign priority to attended to objects over other spatial locations (e.g., McAuliffe, Pratt, & O’Donnell, 2001). To examine this possibility, a fourth experiment was conducted.

### EXPERIMENT 4

The purpose of Experiment 4 was to investigate the question of whether the object-based benefit found in Experiment 3 occurred because some target stimuli at uncued locations appeared within an object while other targets appeared in an empty (nonobject) spatial location. To address this issue, we added two more objects to the display, so that now all four

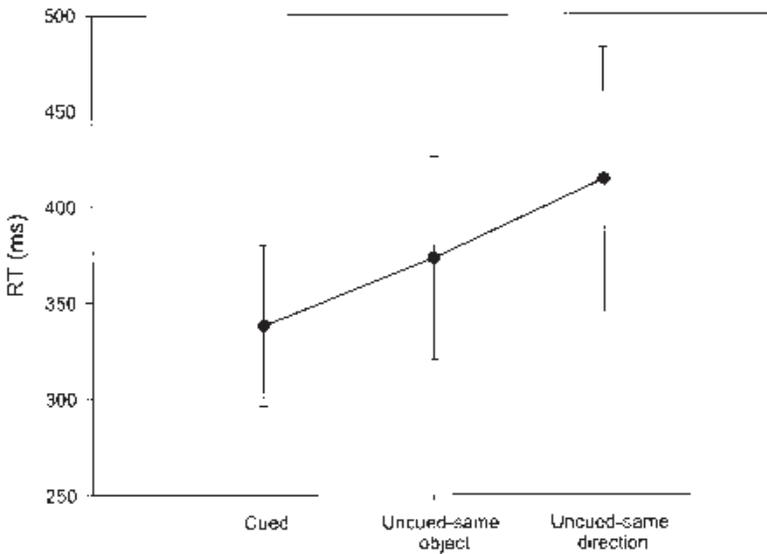


Figure 7. Mean reaction time data for Experiment 3. The error bars reflect the standard error in both directions of the mean. Responses to valid trials were fastest, followed by responses to invalidly cued locations in the same object. Longest RTs were found for responses to invalidly cued locations at the same direction, but in another object.

uncued targets appeared within objects.<sup>4</sup> In addition, to compare RTs of goal-directed hand movements with the same logic regarding direction and position relative to the object as in Experiment 3, the analysis was limited to the trials in which the target stimulus appeared in the upper object. Thus, we compare RTs to exactly the same two locations (on the left and right of fixation) after different invalid cues. If the near object was invalidly cued, the target stimulus appeared in the same direction, but in the other (far) object. In contrast, if the far object was invalidly cued, the target stimulus appeared in the same (far) object, but with another direction. If the RT benefit observed in Experiment 3 was due to the selection of object-based properties for goal-directed responses, the same benefit should be observed in the present experiment. In contrast, if the benefit was due to the fact that the uncued-same-direction targets did not appear in any object, one might expect the same space-based benefit found in Experiment 2 to be present again, with shorter RTs to the target stimulus at an uncued location that does not require a change in direction.<sup>5</sup>

## Method

### *Participants*

The participants were 8 paid undergraduates. They were naive about the purpose of the experiment.

<sup>4</sup>We thank Mieke Donk for pointing out this possible confound.

<sup>5</sup>The fact that cues in the first objects are likely to be identified quicker than cues that are presented in the second object, simply because they are less eccentric, argues against this expectation.

### *Apparatus, procedure, and design*

These were identical to those of Experiment 3 except that two additional objects, and two additional cue locations, were placed on the LED board (see Figure 6B). The new objects were positioned in such a way that the uncued target stimuli presented in the same direction as the cue, as used in the Experiments 2 and 3, appeared within the new objects. Thus, there was no change in the spatial location of the uncued targets, but now all four appeared within objects. The two new cue locations were added to make the objects equivalent with each containing one cue and one uncued location. The same number of trials was used (768), and again the target stimulus occurred at the cued location 75% of the time and at the uncued locations (on the side of the cue) 25% of the time. However, the analysis of the invalid cued locations was limited to the trials in which the target stimulus appeared in the far object. As a consequence, we can compare RTs to exactly the same location, but after different invalid cues. If the far target location was presented after an invalid far cue, responses were made to an uncued position within the same object. However, if the far target location was presented after an invalid near cue, responses were made to an uncued position within the same object. In addition, RTs to valid cues are reported. Interestingly, since responses here are made to exactly the same (invalidly cued) location, we can also compare movement times (MTs) of goal-directed hand movements to exactly the same location, but after invalid cues that were presented in the same or in another object.

## Results and discussion

*Reaction times.* As in the previous experiments, RTs of less than 150 ms were excluded, as were false alarm RTs, and pointing movements that ended at the wrong end-point were excluded. The mean hit rate on target present was 94.3%, and a within-subjects ANOVA on the factor cue (cued–near–object, cued–far–object, uncued–within–object, uncued–within–other–object) showed no significant difference,  $F(3,10) < 1$ .

Mean RTs are shown in Figure 8 and were analysed in a one-way within-subjects ANOVA for the following four cue situations: valid–cue–near–object, valid–cue–far–object, invalid–near–cue–far–target, invalid–far–cue–far–target, respectively. A significant main effect was found,  $F(3, 21) = 12.91$ ,  $p < .001$ , with mean latencies of 283, 305, 357, and 331 ms, respectively. A LSD post hoc test indicated that all four levels were significantly different from each other, all  $ps < .05$ . That is, shortest RTs were found for the validly cued objects. Importantly, however, RTs of goal-directed pointing responses were faster when they were made within the same object (far–cue–far–target; 331 ms) than when they were made at the same direction (far–cue–near–target; 357 ms).

*Movement times.* Mean MTs were analysed in a one-way within-subjects ANOVA for the same four cue-situations: valid–cue–near–object, valid–cue–far–object, invalid–near–cue–far–target, invalid–far–cue–far–target, respectively. A significant main effect was found,  $F(3, 21) = 10.81$ ,  $p < .001$ , with mean movement times of 418, 437, 461, and 462 ms, respectively. Pairwise comparisons (LSD) showed that the valid near and far cues did not significantly differentiate from each other ( $p = .15$ ). The valid near cue did differentiate from the two invalid cues ( $ps < .05$ ), while the valid far cue did not ( $ps > .10$ ). Importantly, however, MTs for invalidly cued responses made within the same object (far–cue–far–target; 461 ms) were equal to those made with the same direction (near–cue–far–target; 462 ms),  $p > .57$ .

Experiment 4 tested the possibility that the object-based advantage found in the previous experiment was because some target stimuli at uncued locations appeared in objects, and some

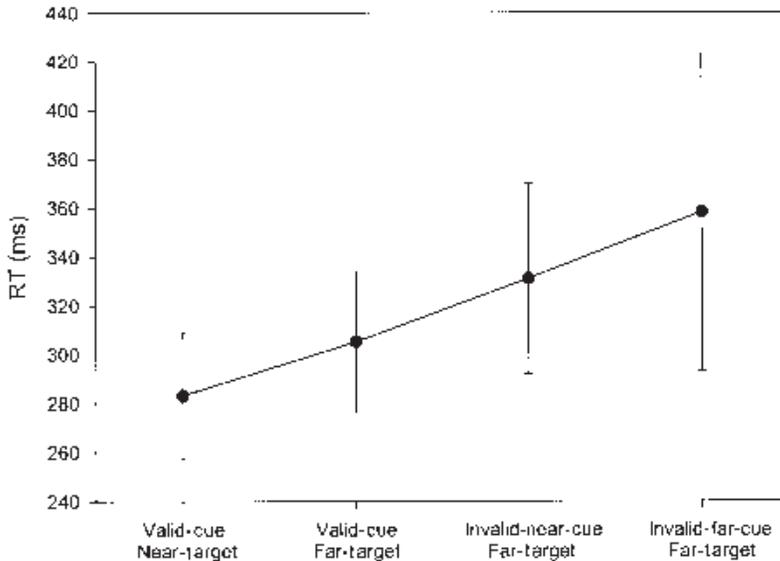


Figure 8. Mean reaction time data for Experiment 4. The error bars reflect the standard error in both directions of the mean. Responses to the validly cued locations in the near and far object yielded the shortest RTs, respectively. Also, RTs for responses to target stimuli that appeared at uncued locations at another direction but in the same object were shorter than those for responses to locations that appeared at the same direction, but in another object.

did not. In addition, a paradigm was developed in which responses to exactly the same location could be compared. The results from the present experiment reject the possibility mentioned above and support the finding that targets in the same object as the cue will be initiated faster than targets that appear in another object. Thus, it appears that object-based selection processes have priority over space-based selection processes in goal-directed pointing movements. However, no such object-based benefit could be detected in the movement times. That is movement times of uncued responses to the same location were similar, independent of whether the target occurred in the same or in another object as did the cue.

## GENERAL DISCUSSION

### Summary of results

The present experiments were designed to examine the contributions of object-based and space-based attentional effects on the preparation time of goal-directed pointing movements. Experiment 1 showed the basic object-based attention effect reported by Egly et al. (1994a, 1994b). Experiment 2 demonstrated that cueing of direction of the upcoming target does facilitate the planning of a goal-directed pointing response. That is, if the target appeared at an uncued location, but in the same direction as the cue, RTs were shorter than when the target appeared at an uncued location that required a change in direction. Experiments 3 and 4 then showed that the direction-based effect observed in Experiment 2 can be overruled by an object-based effect; RTs were shorter for responses to uncued locations within the same object

as the cue, even though such a response required a change in movement direction. Moreover, this pattern of results was found regardless of whether the response to the uncued location that required no change in direction occurred in empty space (Experiment 3) or in another uncued object (Experiment 4).

## Object-based attention for goal-directed movements

There is considerable support for the notion that the visual world is parsed at an early level into objects or perceptual groups and that attention is directed to these groups (e.g., Duncan, 1984; Egly et al., 1994a, 1994b; Kanwisher & Driver, 1992). Indeed, Kahneman and Treisman (1984) have proposed that “attention is assigned to objects, or the locations that objects occupy” and that “attention to irrelevant parts of relevant objects is obligatory” (Kahneman & Treisman, 1984, p. 45). Interestingly, these ideas have often been overlooked when it comes to the study of the preparation of goal-directed responses. This is despite the fact that for quite some years now, more and more scientists have argued that perception, or the perceptual systems, have probably evolved in all species of animals as a means of guiding and controlling action (e.g., Allport, 1987; MacKay, 1966).

The lack of convergence between the object-based attention literature and the movement preparation literature is especially interesting given that most of our actions are object based. That is, most of our actions are directed to grasp various objects, like a glass or cup for drinking, or to manipulate specific details of an object, like in dialling on a phone or typing on a keyboard. Following Allport (1987), the concept of a physical object might be defined as a region of the sensory environment that is invariant with respect to a class of actions that it can support. In other words, the sensory processes necessary to parse the complex visual world depend functionally on the processes of selection for immediate and future actions. The suggestion that selection-for-action is related to an object-level representation is not new and that attention to irrelevant parts of relevant objects is obligatory. The present findings stress this fact for the processes underlying the planning of goal-directed pointing movements as well.

It is worth noting at this point that the effects found in this paper were entirely in the RT component of the overall response time and not in the MT component. This was not wholly unexpected, and the RT component is thought to reflect the time needed to plan the upcoming action, and presumably the effects of object-based attention on actions would be in the planning of the movement. In general, relatively few studies have examined attentional effects on limb movements, and typically RT effects have been much more robust than those found in MT or amplitude (e.g., Pratt & Abrams, 1994; however see also Howard & Tipper, 1997; Meegan & Tipper, 1997, and Tipper, Howard, & Jackson, 1997, for spatial findings).

## Space-based attention for goal-directed movements

Convincing evidence has been reported in the neurophysiological literature that direction is the key control parameter in the specification of a reaching movement. The basic finding is that the activity of single cells in the motor cortex is broadly tuned with respect to the direction of reaching, so that the discharge rate is highest with movements in a preferred direction and

decreases progressively with movements made in directions more and more away from the preferred one (e.g., Georgopoulos, 1995). However, the fact that movements need to be realized in parameters like direction and amplitude does not necessarily mean that at higher levels the response is specified in these same parameters. The present data at the least suggest that visual attention necessary for the planning of goal-directed data also takes nonspatial parameters into account.

The method most widely used to investigate the process of specifying the parameters underlying a response is called the movement precueing technique developed by Rosenbaum (1980). The technique involves first presenting participants with advance partial information (a precue) about spatial parameters of the aiming movement that must be executed. The participant presumably uses this information to partially programme the movement. Next, a go signal is presented that completely defines the required information (i.e., provides the target location) and thus includes whatever information was not contained in the precue. Thus, with this technique, the latency of the movement consists of the time needed to prepare any parameters of the movement that could not be prepared on basis of information in the precue. Rosenbaum found that the specification times were longest for the arm, shorter for direction, and shortest for extent, and that these values were specified serially. Abrams and Jonides (1988) extended this paradigm for saccadic eye movements. They concluded also that the direction and amplitude for an upcoming saccade are calculated separately and not in a fixed order. However, neither study used any objects (which would contain more than one target position) in the visual scene. It may be that in the absence of such objects, cues are processed in a viewer-centred manner (Tipper, Jordan, & Weaver, 1999). Tipper et al. also suggest that in the presence of objects, cues are processed in an action-centred manner, which would be consistent with the present findings.

Another recent finding challenges the commonly held view of the motor cortex being just an "upper motor neuron". Carpenter, Georgopoulos, and Pellizzer (1999) studied the neural encoding in the motor cortex of monkeys during the performance of a context-recall task. Up to five visual stimuli were presented successively on a circle (list presentation), and then one of them changed colour (the test stimulus). The monkey had to make a single hand response toward the stimulus that immediately followed the test stimulus in the list. It was found that changes in neural activity during the list presentation phase reflected the serial order of the stimuli; the effect on cell activity of the serial order stimuli during their presentation was at least as strong as the effect of direction on cell activity during the execution of the hand response.

### Implications for theories of attention

A currently dominant theory in visual attention is the biased competition model (e.g., Desimone & Duncan, 1995; Duncan, 1996). This theory focuses on the interplay between bottom-up and top-down sources of attention. Features of an attended object are processed concurrently, but the limitation of the ability to deal simultaneously with several sources of visual information determines the number of separate objects that can be seen. Due to these limitations in cognitive processing capacity a selective attentional system should operate to restrict the huge amount of potential inputs and withhold information irrelevant to the

current behaviour. Thus, a competition for representation, analysis, and control of behaviour among visual objects takes place. The preactivated target units have an advantage in this competition (Duncan, 1996). More specifically, within brain systems receiving visual input, a gain in activation for one object entails a loss to activation for other objects. For instance, Duncan (1984) indicated that two attributes of a single object (e.g., brightness and orientation) could be identified simultaneously without mutual interference, while attributes of two different objects could not, even if the objects spatially overlap. The object-based theory suggests that focal attention is guided by parallel, preattentive processes representing discrete objects (Duncan, 1984). One plausible cause for this competition might be the structure of cortical areas in both the ventral and dorsal visual stream. As the complexity of visual processing increases in every consecutive area, receptive field sizes of individual neurons increase. When more objects are added to the receptive field, the information about any given individual object must decline. Desimone and Duncan propose competition between objects represented by the same receptive field. Here, the importance in terms of behaviour plays a role: The competition is biased towards information relevant to the current behaviour. The information in a visual scene determines the spatial distribution and feature attributes of objects. Clearly, behaviour is typically directed to objects at a specific location rather than to space per se.

The selection-for-action hypothesis (Allport, 1987, 1993) provides another model for visual processing. In his 1993 article, Allport pointed out that since the 1950s the majority of research in the area of visual attention considers the limited information-processing capacity of the brain as the fundamental constraint underlying all operations of attention. Thus, according to this view the selection function of attention arises from the limited capacity of the information-processing system. Diverging from the general idea that attention operates as a mechanism for coping with central limited capacities of cognitive processing, Allport emphasizes the constraints in preparation and control of action. The idea behind the selection-for-action perspective is that integrated actions require the selection of particular aspects or attributes from the environment that are relevant to this action at hand. At the same time, the information irrelevant to the action should be ignored. Thus, the attentional processes are viewed as the selection of action-relevant events or stimuli relying on particular action plans. Reasons for this argumentation emerge from the experience that selecting a stimulus as a target for a saccade occurs before the foveation. In addition, phenomenon of covert attention suggests that foveation is neither necessary nor a sufficient condition for selection (see Allport, 1987). During the perception of an object, information about different attributes of that object should be bound together to allow the purposeful use of the object according to intended action. If the intention is to take a yellow dictionary out of the bookshelf, the information eventually about colour, size, and orientation should be combined for an accurate grasping movement. Also here, the selection of particular aspects for the planning of an action is likely to exist at an object rather than space level.

To sum up, both the biased competition theory and the selection-for-action theory offer a framework to understand object-based preferences above pure spatial-based preferences in the preparation phase of goal-directed movements. However, the biased competition theory stresses the competition at the input level, whereas the selection-for-action theory emphasizes the action selection parameters. At present, more specific theoretical assumptions have to be developed to disentangle the theories experimentally.

## Neurophysiological substrates

Goodale and Milner have supplied considerable converging evidence that there are separate visual pathways for perception and action (Goodale & Milner, 1992; Milner & Goodale, 1993). They argue that the set of object descriptions that permit identification and recognition may be computed independently of the set of descriptions that allow an observer to shape the hand appropriately to pick up an object. The “what” system is located in the ventral stream of projections from the striate cortex to the inferotemporal cortex, while the dorsal stream projecting from the striate cortex to the posterior parietal region mediates the “how” system. Processes that occur early in the visual processing stream (i.e., before or at primary visual cortex) will be carried by both “what” and “how” systems, while later occurring processes will have their effect in one system or the other. The present findings are consistent with the former, as the selection of the target imbedded in an object produced both object-based attention and object-based reaching effects. Support for early object selection comes from a study by Edwards and Humphreys (2002; see also Roelfsema, Lamme, & Spekreijse, 1998), which examined perceptual and bimanual responses to various targets with Balint’s syndrome patient GK. Edwards and Humphreys note that their results “suggest that both perceptual report and action can proceed through a common processing stage of visual selection” (p. 459).

Additional evidence for interactions between the two streams of visual processing has been demonstrated extensively at a neurophysiological level (see for a review, Rossetti & Pisella, 2002). More specifically, evidence that a visual parsing mechanism is directly related to upcoming actions has also been reported in different areas of the brain. For example, in one study of inferotemporal neurons in macaque monkey (Chelazzi, Miller, Duncan, & Desimone, 1993), an initial cue stimulus was followed by an array of 2–5 test items, and the monkeys were required to make a saccade to an item in the test array that matched the cue stimulus. The stimuli were chosen such that one stimulus was effective in driving the neuron being recorded, and the others were ineffective. As a result, the neuron’s response to the test array reflected the processing of the one item that matched the stimulus preferences of the neuron. In the period following the cue stimulus, firing rates were found to be maintained at a higher level when the cue stimulus was an effective stimulus for the neuron than when the cue was an ineffective stimulus. This prolonged activation of neurons that code the features of the cue stimulus may reflect a target template that is used to select the target item from the distractor items in the test array (Luck, 1994). When the test array was subsequently presented, the initial response was the same whether or not the one effective stimulus within the array matched the cue. Importantly, however, the response became suppressed if the effective stimulus was a nontarget, but was maintained at a high level if the effective stimulus was the target for the subsequent saccade, indicating a close connection between template-like activation following a cue stimulus and suppression of nontarget information following the test array.

Together, the behavioural and neurophysiological research strongly indicates that there is a strong relationship between object selection and response planning. As found by the present study (and in Edwards & Humphreys, 2002), this occurs even when the perceptual objects (or perceptual grouping effects in the case of Edwards & Humphreys, 2002) are largely irrelevant to the response. After all, taking into account a rectangular paper frame does not directly benefit pointing to an LED target. However, it seems likely that these systems have evolved to

optimize our behaviour to the types of object we typically manipulate in everyday life—relatively small objects (e.g., from furniture to pencils) in which taking into account the entire object is much more efficient than only attending to a the limited portion of the object that we are directly in contact with.

To conclude, previous work has tended to support object-based selection processes for visual attention tasks and space-based selection processes for goal-directed actions. The present set of experiments confirms both notions. However, if spatial-based cues and object-based cues are combined, selection processes for goal-directed actions seem to be primarily object based.

## REFERENCES

- Abrams, R. A., & Jonides, J. (1988). Programming saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 428–443.
- Abrams, R. A., & Law, M. B. (2000). Object-based visual attention with endogenous orienting. *Perception & Psychophysics*, *62*, 818–833.
- Alexander, G. E., & Crutcher, M. D. (1990). Preparation for movement: Neural representation of intended direction in three motor areas of the monkey. *Journal of Neurophysiology*, *64*, 133–150.
- Allport, A. (1987). Selection for action: Some behavioural and neurophysiological considerations of attention and action. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395–419). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Allport, A. (1993). Attention and control: Have we been asking the wrong questions? A critical review of twenty-five years. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience* (pp. 183–218). Cambridge, MA: MIT Press.
- Ashe, J., & Georgopoulos, A. P. (1994). Movement parameters and neural activity in motor cortex and area 5. *Cerebral Cortex*, *4*, 590–600.
- Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effects of grouping. *Perception & Psychophysics*, *51*, 145–162.
- Bennett, P. J., & Pratt, J. (2001). The spatial distribution of inhibition of return. *Psychological Science*, *12*, 76–80.
- Carpenter, A. F., Georgopoulos, A. P., & Pelizzier, G. (1999). Motor cortical encoding of serial order in a context-recall task. *Science*, *283*, 1752–1757.
- Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal cortex. *Nature*, *363*, 345–347.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review in Neuroscience*, *18*, 193–222.
- Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, *113*, 501–517.
- Duncan, J. (1996). Cooperating brain systems in selective perception and action. In T. Inui and J. L. McClelland (Eds.), *Attention and performance XVI: Information integration in perception and communication* (pp. 549–578). Cambridge, MA: MIT Press.
- Edwards, M. G., & Humphreys, G. W. (2002). Visual selection and action in Balint's syndrome. *Cognitive Neuropsychology*, *19*, 445–462.
- Egly, R., Driver, J., & Rafal, R. D. (1994b). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, *123*, 161–177.
- Egly, R., Rafal, R. D., Driver, J., & Starrveveld, Y. (1994a). Covert orienting in the split brain reveals hemispheric specialization for object-based attention. *Psychological Science*, *5*, 380–383.
- 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.
- Georgopoulos, A. P. (1986). On reaching. *Annual Review of Neuroscience*, *9*, 9147–9170.
- Georgopoulos, A. P. (1995). Motor cortex and cognitive processing. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 507–517). Cambridge, MA: MIT Press.

- Georgopoulos, A. P. (2000). Neural aspects of cognitive motor control. *Current Opinion in Neurobiology*, *10*, 238–241.
- Georgopoulos, A. P., Kalaska, J. F., Caminiti, R., & Massey, J. T. (1982). On the relations between the direction of two-dimensional arm movements and cell discharge in primate motor cortex. *Journal of Neuroscience*, *2*, 1527–1537.
- Godijn, R., & Pratt, J. (2002). Endogenous saccades are preceded by shifts of visual attention: Evidence from cross-saccadic priming effects. *Acta Psychologica*, *110*, 83–102.
- Goldsmith, M. (1998). What's in a location? Comparing object-based and space-based models of feature integration in visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *127*, 189–219.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*, 20–25.
- Hillstrom, A. P., & Yantis, S. (1994). Visual motion and attentional capture. *Perception & Psychophysics*, *55*, 399–411.
- Howard, L. A., & Tipper, S. P. (1997). Hand deviations away from visual cues: Indirect evidence for inhibition. *Experimental Brain Research*, *113*, 144–152.
- Kahneman, D., & Treisman, A. M. (1984). Changing views of attention and automaticity. In R. Parasuraman, R. Davies, & J. Beatty (Eds.), *Variety of attention*. New York: Academic Press.
- Kanwisher, N., & Driver, J. (1992). Objects, attributes, and visual attention: Which, what and where. *Psychological Science*, *1*, 26–31.
- Kramer, A. F., & Weber, T. A. (1999). Object-based attentional selection and aging. *Psychology & Aging*, *14*, 99–107.
- Laberge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review*, *96*, 101–124.
- Larry, D., & Egeth, H. (2002). Object-based selection: The role of attentional shifts. *Perception & Psychophysics*, *64*, 52–66.
- Luck, S. J. (1994). Cognitive and neural mechanisms of visual search. *Current Opinion in Neurobiology*, *4*, 183–188.
- MacKay, D. M. (1966). Cerebral organization and the conscious control of action. In J. C. Eccles (Ed.), *Brain and conscious experience*. New York: Springer.
- McAuliffe, J., Pratt, J., & O'Donnell, C. (2001). Examining location-based and object-based components of inhibition of return. *Perception & Psychophysics*, *63*, 1072–1082.
- Meegan, D. V., & Tipper, S. P. (1997). Reaching into cluttered visual environments: Spatial and temporal influences of distracting objects. *Quarterly Journal of Experimental Psychology*, *51A*, 225–249.
- Milner, A. D., & Goodale, M. A. (1993). Visual pathways to perception and action. *Progression in Brain Research*, *95*, 317–337.
- Moore, C. M., Yantis, S., & Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science*, *9*, 104–110.
- Neggers, S. F. W., & Bekkering, H. (2000). Ocular gaze is anchored to the target of an ongoing pointing movement. *Journal of Neurophysiology*, *83*, 639–651.
- Neggers, S. F. W., & Bekkering, H. (2001). Gaze anchoring to a pointing target is present during the entire pointing movement and is driven by a non-visual signal. *Journal of Neurophysiology*, *86*, 961–970.
- Pellizzer, G., Sargent, P., & Georgopoulos, A. P. (1995). Motor cortical activity in a context-recall task. *Science*, *269*, 702–705.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.
- Pratt, J., & Abrams, R. A. (1994). Action-centered inhibition: Effects of distractors on movement planning and execution. *Human Movement Science*, *13*, 245–254.
- Pratt, J., & Sekuler, A. B. (2001). The effects of occlusion and past experience on the allocation of object-based attention. *Psychonomic Bulletin & Review*, *8*, 721–777.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favour of a premotor theory of attention. *Neuropsychologia*, *25*, 31–40.
- Roelfsema, P. R., Lamme, V. A. F., & Spekreijse, H. (1998). Object-based attention in the primary visual cortex of the macaque monkey. *Nature*, *395*, 376–381.
- Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction and extent. *Journal of Experimental Psychology: General*, *109*, 444–474.
- Rossetti, Y., & Pisella, L. (2002). Tutorial: Several 'vision for action' systems: A guide to dissociation and integrating dorsal and ventral functions. In W. Prinz and B. Hommel (Eds.), *Attention and Performance XIX: Common mechanisms in perception and action* (pp. 62–119). Oxford, UK: Oxford University Press.

- Shepherd, M., Findlay, J. M., & Hockey, R. J. (1986). The relationship between eye movements and spatial attention. *Quarterly Journal of Experimental Psychology*, *38A*, 475–491.
- Tipper, S. P., Howard, L. A., & Jackson, S. R. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition*, *4*, 1–38.
- Tipper, S. P., Jordan, H., & Weaver, B. (1999). Scene-based and object-centred inhibition of return: Evidence for dual orienting mechanisms. *Perception & Psychophysics*, *61*, 50–60.
- Tipper, S. P., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 891–905.
- Tipper, S. P., Rafal, R., Reuter-Lorenz, P. A., Starrveveld, Y., Ro, T., Egly, R., et al. (1997). Object-based facilitation and inhibition from visual orienting in the human split-brain. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 1522–1532.

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