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Action modulates object-based selection

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Abstract

Cueing attention to one part of an object can facilitate discrimination in another part (Experiment 1 [Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*, 501–517]; [Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: Human Perception and Performance, 123*, 161–177]). We show that this object-based mediation of attention is disrupted when a pointing movement is prepared to the cued part; when a pointing response is prepared to a part of an object, discrimination does not differ between (i) stimuli at locations in the same object but distant to the part where the pointing movement is programmed and (ii) stimuli at locations equidistant from the movement but outside the object (Experiment 2). This remains true even when the pointing movement cannot be performed without first coding the whole object (Experiment 3). Our results indicate that pointing either (i) emphasizes spatial selection at the expense of object-based selection, or (ii) changes the nature of the representation(s) mediating perceptual selection. In addition, the results indicate that there can be a distinct effect on attention of movement to a specific location, separate from the top-down cueing of attention to another position (Experiment 3). Our data highlight the interactivity between perception and action.

Keywords: Action; Perception; Visual attention; Visuomotor control; Object perception; Visual grouping

1. Introduction

Our ability to identify briefly presented stimuli is strongly influenced by the simultaneous requirement to make an action. Deubel, Schneider, and Paprotta (1998) have shown that identification is improved if we point to a location where a stimulus appears, relative to when we point to another location close by. They cued participants to point to a particular object within a horizontal array of objects, arranged different distances left and right of fixation. Before the pointing movement had been launched, but at a time when it had already been programmed, one discrimination probe (either 'ㅌ' or '∃'), and multiple distractors ('ㄹ' or 'Ƨ') were briefly presented, one on each object. When the probe fell on the object to which a movement had been programmed, discrimination performance was better than when it fell at other locations. Indeed, performance at the cued location was even better than in a discrimination-only baseline condition where no movements were required. Deubel et al. argued that, the better the discrimination performance, the more attention had been allocated to the probe. It follows that visual attention may be coupled to pointing movements, such that attention is allocated to objects to which movements are planned. Furthermore, Deubel et al. showed evidence for coupling even when the probe occurred at a predictable location (on the same object) on every

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trial; then, discrimination was better when the pointing movement was made to the object containing the probe than when it was made to any other object. Apparently, the coupling between pointing movements and attention is mandatory: participants fail to attend away from the end location of a pointing movement towards a probe in another location, even when the location of the probe is predictable.

Other evidence for there being a close inter-play between action and attention comes from work on 'negative priming' and on the effects of different actions on attention. Tipper and colleagues (e.g., Tipper, Lortie, & Baylis, 1992) required participants to make a pointing response to a target that appeared along with a distractor. On a subsequent trial, the target could fall at the same location as the distractor on the preceding trial. On such occasions, reaction times to initiate the pointing movement (RTs) were slowed relative to when the target and the earlier distractor appeared at different locations. This 'negative priming' effect was greater when distractors fell close to the responding hand, suggesting that attentional inhibition of distractor locations occurred in a hand-based reference frame, sensitive to the distance between a distractor and the effector. In another study, Bekkering and Neggers (2002) had participants carry out visual search tasks for targets defined by their orientation and colour. The task was either to point to or to grasp the target. Bekkering and Neggers found that fixations were biased towards distractors that shared their orientation with the expected target, but that this was more likely when the target had to be grasped (when the target's orientation was relevant) compared to when a pointing response was made. Apparently the particular action required influenced the 'weighting' of perceptual features for attention; orientation was weighted more strongly when grasping than when pointing. This result follows earlier neuropsychological studies demonstrating that cueing a patient to make an action reduced the degree of visual neglect in a search task, but only when the acted-upon object was oriented to match the action (Humphreys & Riddoch, 2001). Again, preparing an action biased attention to object properties matching the action.

Though these findings suggest that action is intimately coupled to perceptual selection, the data do not provide detailed information on the mechanisms underlying this coupling. For example, is the coupling dependent on enhanced processing at the *location* to which the action is directed, or is it dependent on enhanced processing of the *object* to which the action is made? It is well established that perceptual report of the second of two spatially separated stimulus attributes is better if the second attribute belongs to the same object as the attribute first reported (Duncan, 1984; Vecera & Farah, 1994). Similarly, cueing attention to one part of an object can facilitate responses to a target presented at a different location in the same object, compared with when the target appears an equal distance away from the cue but in a different object (Egly, Driver, & Rafal, 1994). This suggests that parts of an object are grouped, so that attention spreads across the group and its parts are selected together. Indeed, sub-parts of an object can be difficult to select independently (Rensink & Enns, 1995). However, consider what may happen when we make an action to a part of an object (e.g., pointing to the handle of a cup). What is selected under these circumstances, the whole object (the cup) or the part (the handle)? Does grouping modulate the coupling between action and attention, so that attention spreads across the object even when the action is made to just a part? Models of how action affects perception can make different predictions on this point, depending on factors such as the strength of grouping parts into objects and the magnitude of cueing from the action; essentially, either there can be object influences or an influence of action to just the part, depending on the relative strengths of activation between object representations and action cueing respectively (e.g., Duncan, Humphreys, & Ward, 1997; Schneider, 1995). Furthermore, as indicated by the evidence from Bekkering and Neggers (2002) and Humphreys and Riddoch (2001), any interaction between action and perception may depend on the particular action being made.

Whether object-coding modulates the effects of action on attention has recently been examined in a number of studies. Bekkering and Pratt (2004), for example, measured the time taken to initiate a pointing response to a visual target. On the majority of trials, the appearance of the target was preceded by a briefly presented cue, that signalled the impending location of the target. On a minority of trials, the target appeared in a different location from the cue, either within the same object as the cue or in a different object (but was always displaced in the same direction for any adjustment of the pointing response, relative to the cue). Bekkering and Pratt found that RTs to initiate pointing movements were faster when the target fell within the same object as the cue compared with when the cue and target appeared in different objects (consistent with the findings of Egly et al., 1994). They concluded that the coupling between goal-directed pointing responses and attention reflected object-based coding and the allocation of attention to whole objects. Fischer and Hoellen (2004) used a quite similar procedure, but measured movement duration (MT) in addition to the time to initiate movement (RT), and examined grasping movements as well as pointing movements. In contrast to Bekkering and Pratt (2004), they found effects of spatial separation but no object-based effects on the RTs to initiate pointing responses to a target. They found exactly the same when they examined movements durations (MTs) to complete pointing movements. Strong effects of the spatial separation between the cue and the target also occurred when the task was to grasp a raised part of the object adjacent to where the target appeared.[1] However, in this case there was in addition an effect of whether the target appeared in the same object as the cue: the RT to initiate the movement, in particular, was faster when the target fell in the same object as the cue. These results suggest that object-based coding can play a role in the interaction between action and attention, though this may depend upon the action (Fischer & Hoellen, 2004): grasping may be more susceptible to the effects of object-coding than pointing. On the other hand, since the task was to move to the target and the target was preceded by an attentional cue, it is possible that attention was deployed to the cue prior to any action being programmed (with action programming waiting on the subsequent presentation of the target). In this case, the RT to initiate a movement to the target may reflect the initial object-based allocation of visual attention to the cue and its visual context, so that movements to targets falling in the same object as the cue are initiated faster than movements to targets falling in a different object. Note that Bekkering and Pratt (2004) measured movement initiation time (RT) only, and Fischer and Hoellen (2004) found reliable effects of object coding on movement initiation time, but not on movement duration (where action programming may have had time to impact). The situation in these studies might differ from one in which the cue is used to program an action to a given target location irrespective of where a visual probe subsequently appears (with the probe either falling at the same or a different location to the endpoint of the pre-programmed action). It is only in this last case that we can observe effects of action programming on attention. Does object-coding influence the allocation of attention under such conditions?

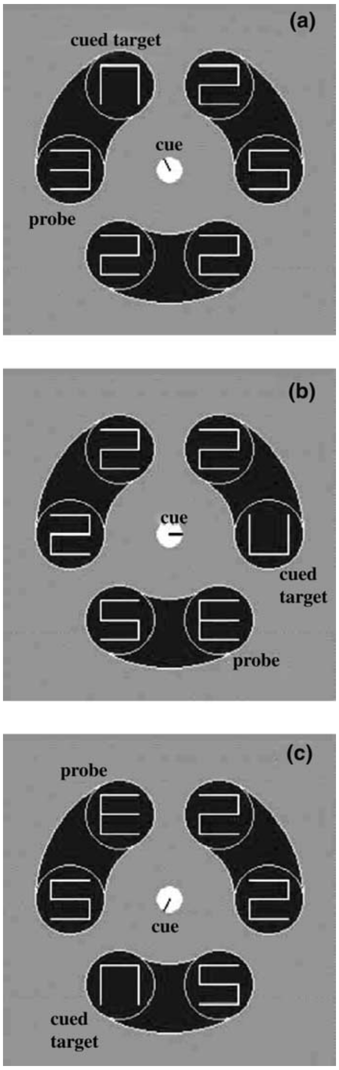

Fig. 1. Example displays from Experiment 1. Cued targets and probes are (a) 1 circle away, within the same object ('1, within-object'); (b) 1 circle away, within a different object ('1, across-object'); and (c) 2 circles away, within a different object ('2, across-object').

To test for the effects of object-based coding on attention when an action is already pre-programmed, we adapted the procedure pioneered by Deubel et al. (1998) (see also Deubel & Schneider, 1996, 2004), and we had participants make pointing responses. Note that Fischer and Hoellen's (2004) data suggest that pointing responses may reduce object-based influences on selection, even under conditions where attention is cued before the target for the pointing response appears. In our adaptation of Deubel et al. (1998), we used displays containing elongated objects with two spatially distinguishable parts or ends that nevertheless grouped on the basis of connectedness, common movement and surface colour (see Fig. 1). Our primary interest was in trials where the end location of the pre-programmed motor response differed from the location where the probe appeared. We asked whether there was better selection (and report) of such a probe when the probe and the pointing response fell within (different parts of) the same object than when they fell in different objects. We report three experiments. In Experiment 1, we began by providing evidence that attention did spread across the parts of objects in the absence of pointing movements. To do this, we followed the logic of Duncan (1984) and examined the impact of a first target discrimination ('⊔' or '⊓') at a cued location on a second probe discrimination ('E' or 'Ǝ') at an uncued location. The probe could fall within the same or within a different object compared with the cued target, at a fixed separation from it. We confirmed an object-based benefit when the cued target and the probe fell within

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[1] The stimuli were two dimensional elongated shapes presented on a computer screen, similar to those of Egly et al. (1994). In the 'grasp' condition, small pieces of blu-tack were placed at the ends of the shapes, adjacent to where the target would appear. The task was to grasp the blu-tack that was proximal to the location of the target.

the same object. In Experiments 2 and 3, we used the same displays as in Experiment 1 to examine the impact of a programmed pointing movement to one cued location (or object part) on discrimination of a probe ('ㅌ' or '∃', as in Experiment 1) at an uncued location. The pointing movement and the probe could fall either within the same or within different objects, at a constant separation in these two cases. We ask whether the effect of object-coding on visual discrimination of the probe remained even when a pointing movement was programmed to a different part of an object to the part containing the probe. In Experiment 2, participants pointed directly to the object part that was indicated by a central cue. In Experiment 3, in contrast, participants pointed to an object part *adjacent* to the cued object part; depending on the task demand, the object part pointed to either was or was not part of the cued object. Such 'object contingent' pointing should emphasize object coding, thus maximising the chances of finding object-based effects on selection.

One other attribute of Experiment 3 is that it enabled us to separate effects on selection due to movement from effects due to the presentation of the central (endogenous) cue signalling the movement location. In previous studies of the effects of movement on selection, investigators have typically had participants move to a location directly indicated by a visual cue (e.g., Deubel et al., 1998). In these circumstances, movement could facilitate probe discrimination by enhancing a separate effect from central (endogenous) cueing of attention, rather than by affecting selection directly. In Experiment 3, a pointing action was made to a location other than that indicated by the central cue. By separating the location indicated by the cue from the end location of the movement, we can evaluate whether there is an effect of action on selection independent of effects of endogenous visual cueing.

1.1. General method

1.1.1. Experimental setup

The apparatus is illustrated in Fig. 2. A PC running DOS-based in-house software was used to control stimulus presentation with millisecond accuracy, and to record discrimination responses. The stimuli were displayed on a SONY Trinitron 19-in. VGA colour monitor. The monitor was suspended upside-down over the participant's head, in a semi-darkened room. The stimuli displayed on the monitor were viewed—via a one-way mirror—projected down onto an appropriately angled base plane (that was also the pointing plane in Experiments 2 and 3). The participant viewed the projected image by resting his or her head in goggles suspended above the one-way mirror; these goggles fixed the viewing distance at 53 cm. The index finger and middle finger of the participant's non-dominant (left) hand were rested on two buttons of a button box, connected to the two buttons on the mouse of the stimulus-presentation PC. By depressing one of the two buttons on the box, participants signalled their discrimination responses.

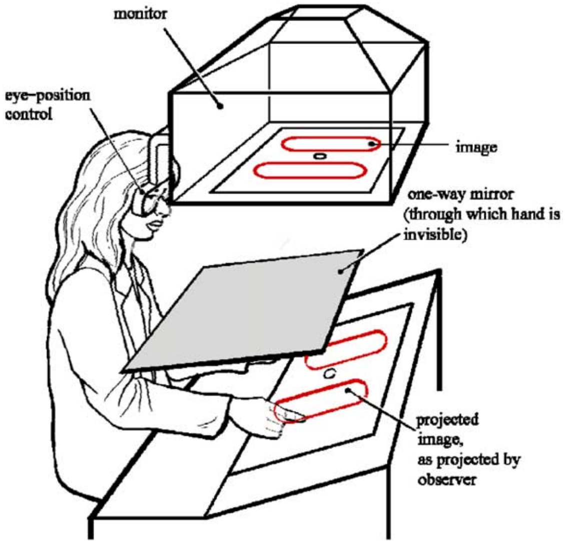

Fig. 2. The experimental setup used for the experiments. The stimuli were generated by a monitor suspended over the participant's head, and were viewed, via a half-silvered mirror, projected down onto a base plane under the mirror (the stimuli depicted in the figure are from a different study involving four, not six, display locations). The room was darkened, so that no visual information was available from the under-side of the mirror. Thus, pointing movements on the base plane appeared to be made directly to the visual stimuli, while, at the same time, being invisible.

1.1.2. Stimuli and procedure

Displays always contained six circles, presented equally spaced around a virtual circle centred on a fixation cross; adjacent pairs of circles were connected to form three 'objects' (see Fig. 1). On each trial, a probe (either 'ㅌ' or '∃') was exposed inside one of the six display circles. In Experiment 1 only, a target stimulus ('⊔' or '⊓') was presented inside one of the other circles. Circles not otherwise occupied contained a distractor stimulus (either 'ㄹ' or 'S'). At the start of each trial, a central arrow cue indicated either the circle where the target stimulus ('⊔' or '⊓') would fall in Experiment 1, or, in Experiments 2 and 3, the circle that was the end-location of the pointing movement. In Experiment 1, the task was to discriminate the target in the cued location, and then to discriminate the probe stimulus in any of the uncued locations. In Experiments 2 and 3, the task was to make a speeded pointing movement to the cued location, and then, as in Experiment 1, to discriminate the probe.

1.1.3. Design

We were interested in probe discrimination as a function of either the relative locations of the cued target stimulus and the probe (Experiment 1), or the cued endpoint of a pointing movement and the probe (Experiments 2 and 3). The probe could appear at various locations relative to the cued target stimulus or pointing movement: (a) one circle away but in the same object ('1, within object'); (b) one circle away but in a different object ('1, across object'); (c) two circles away in a different object ('2, across object'); and (d) three circles away on the opposite side of the display, in a different object ('3, across object'). If there is 'object-based' selection of the grouped circles, then report of the probe stimulus should be better in the '1, within-object' condition than when it occurs the same distance from the cued stimulus/movement endpoint, but in a different object ('1, across-object'). On the other hand, if there is an effect of spatial distance on selection, then the probe stimulus should be better reported when it is in a circle close to the cued stimulus/movement endpoint ('1, across') than when it is in a more distant circle (in the '2, across' or '3, across' conditions).

2. Experiment 1: Object-based selection without movement

2.1. Method

2.1.1. Participants

Six participants took part. Their ages ranged from 19 to 25 years. Five of the participants were male and one female. All of the participants were right-handed, had normal or corrected-to-normal vision, and were naïve with respect to the aim of the study.

2.1.2. Stimuli

Fig. 1 shows some typical displays. The displays contained six white circles (luminance 12 cd/m^2) of radius 13.5 mm (1.5 deg) with their midpoints arranged at 0, 60, 120, 180, 240, and 300 deg (where 0 deg is equated with the 3-o'clock direction) around a virtual circle with radius 38.5 mm (4.2 deg). The six circles were grouped into three 'objects'. This was done by colouring the centre of each circle and the regions connecting the three pairs of circles red (depicted as black in Fig. 1), and by outlining the connecting regions in the same white as that used to draw the white circles. The red colour defining the three objects had a luminance of 3 cd/m^2, the same as the luminance of the grey background. (The background brightness was high in order to avoid the effects of phosphor persistence; Wolf & Deubel, 1997.) At various stages of a trial, the six circles were either (i) all empty, (ii) all filled with '⊟'s which served as masks for distractor, target, and probe stimuli, or (iii) four of them filled with a distractor stimulus—either 'ㄹ' or 'S'—one of them filled with the probe stimulus—either 'ㅌ' or '∃'—and the final one filled with the cued target stimulus—either '⊔' or '⊓' (see Fig. 1). Across trials, both the cued target and the probe were equally distributed across the six possible circles, with all possible relative arrangements of cued-target and probe equally represented (see Section 2.1.4). The mask, probe, target and distractor characters all had a luminance of 28 cd/m^2 and a height and width of 15.5 mm (1.7 deg). At the centre of the virtual circle around which the six white circles were arranged was a small grey circle (luminance 12 cd/m^2) with a radius of 5 mm (0.5 deg). It formed the backdrop for the cue, which was a 5-mm long (0.5-deg) dark line (luminance 0 cd/m^2) that could appear along any one of the six radii of the virtual circle that pointed towards the six white circles (see Fig. 1).

2.1.3. Procedure

The sequence of events constituting each trial is summarised in Fig. 3 (although frame 4 in Fig. 3 applies to Experiments 2 and 3, in which only one item, the probe, had to be reported). Participants were asked to fixate on the central grey circle throughout the trial. It was explained that eye movements would impair overall discrimination performance. At the start of each trial, the three objects started to pulsate around their centres of gravity (see frame 1 in Fig. 3). This was done by rapidly alternating (at a rate of 5 Hz) between normal-sized views of the objects and slightly larger views (see the dashed lines in frame 1). This pulsation procedure was introduced to increase the perceptual integrity of each of the three objects. The pulsating ceased after 3 s and the display was then static for 200 ms (see frame 2 in Fig. 3). Next, the cue (a black line in the central circle) and pre-stimulus masks (six '⊟'s in each of the six circles) were presented (frame 3, Fig. 3). The cue pointed in the direction of the circle that would contain the cued target. The cue and the masks were visible together for 100 ms. After this, the cue remained visible but the pre-stimulus masks were replaced, the one in the cued location by the cued target ('⊔' or '⊓'), any one of the remaining five by the probe ('ㅌ' or '∃') and the remaining four by distractors ('ㄹ' or 'S'; see Fig. 1). The target, probe and distractor stimuli remained visible for just 140 ms, to minimise effects of eye movements on performance. When the 140 ms had elapsed, the target, probe and distractor stimuli were replaced with post-stimulus masks ('⊟'s; see frame 5 in Fig. 3).

One second after the post-stimulus masks were displayed, a beep sounded signalling that the participant should make an unspeeded discrimination response to the identity of the target in the cued location (left button for '⊔', right button for '⊓'). One second after the first discrimination response, another beep signalled the participant to make a second unspeeded discrimination response to the identity of the probe (left button of the button-box for 'ㅌ', right button for '∃'). After this second discrimination response, the post-stimulus masks and

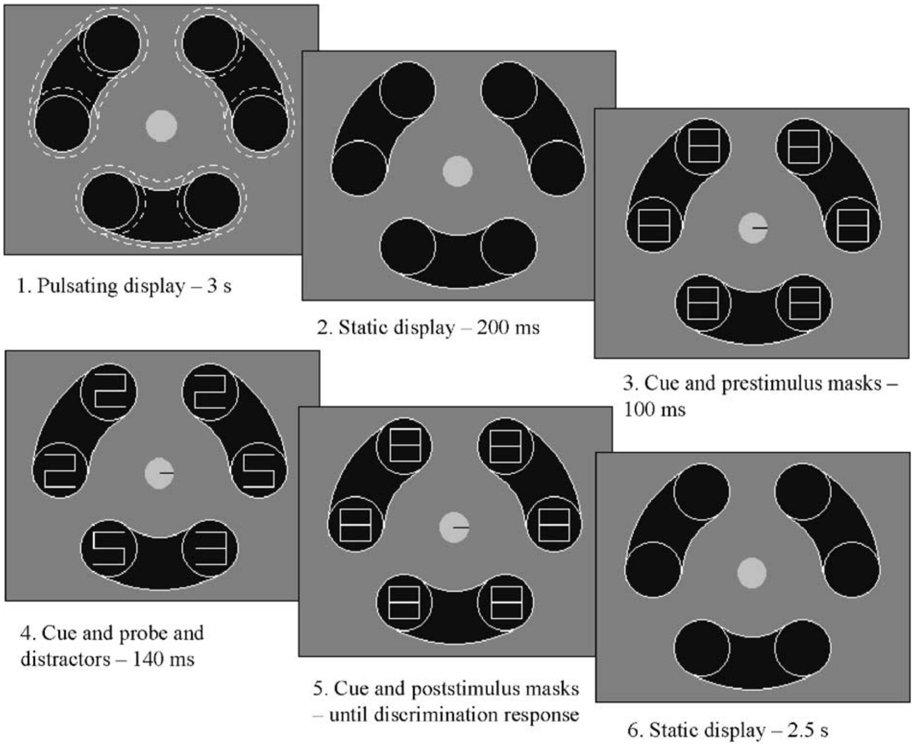

Fig. 3. The display at various points of an experimental trial in Experiments 2 and 3. The six movement and probe locations are circumscribed by six white circles and grouped into three 'objects'. In the middle of the trial, five distractors ('ㄹ' or 'Ƨ') and one probe ('ㅌ', or, as in this case, '∃') were arranged one inside each of the white circles (see frame 4 of the figure), with the location of the probe being randomised across trials. The cue is the dark line in the central circle. The procedure in Experiment 1 was the same except that a 'cued' target ('⊔' or '⊓') appeared at the cued location (see Fig. 1). Participants in Experiment 1 were asked to decide, in a 2AFC procedure, the identity of first the cued target and then the probe. In Experiments 2 and 3, participants used the cue to move in accordance with the task instructions, and then made a 2AFC-decision concerning the identity of the probe.

the cue were removed, leaving just the three objects and the central circle for 0.5 s.

Trials were always presented in blocks of 120 trials that took approximately 20 min to complete. The experiment consisted of four blocks of 120 trials. The four blocks together were completed in one session. Before completing the four experimental blocks, all participants had to attain a criterion level of performance in a practice session. The practice session started with blocks of trials on which participants had only to discriminate the identity of the cued target. Participants had to achieve 80% correct discriminations within a block of trials, before moving on. They then had to perform probe discrimination alone, until they achieved a score of 65% correct on any block. In the final part of the practice session, participants performed both cued-target and probe discriminations, just as in the dual-task blocks of the experiment proper. The practice session ended when a block of trials was completed in which 80% of the cued-target and 60% of the probe discriminations were correct.

2.1.4. Design

There were two independent variables, the location of the cued target (1 of 6 locations) and the location of the probe relative to the cued target (1 of 5 relative locations: (1) one circle away, within the same object—'1, within object'; (2) one circle away, in a different object—'1, across object'; (3) two circles away in a clockwise direction, in a different object—'2+, across object'; (4) two circles away in an anti-clockwise direction, in a different object—'2−, across object'; (5) three circles away on the opposite side of the display, in a different object—'3, across-object'). Each block of 120 trials contained 4 trials for each of the 30 combinations of 6 cued-target and 5 cued-target/probe relative locations. The ordering of the different trial-types was randomly determined within each block. The dependent variable was discrimination performance with the probe, measured as a function of its location relative to that of the cued target, averaged across the six cued-target locations.

2.2. Results

For trials on which the cued target was correctly discriminated, the percent-correct probe discrimination was broken down as a function of the relative locations of the probe and cued-target stimuli, collapsed across the six possible cued-target locations. This generated five

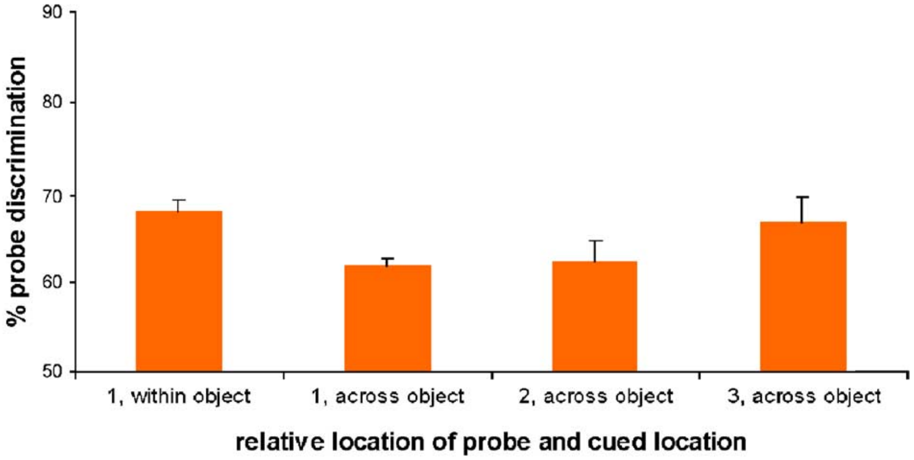

Fig. 4. Experiment 1: Group-mean percent-correct probe discrimination for the four relative-location conditions. Bars indicate standard errors.

measurements, one for each level of 'relative-location': '1, within object', '1, across object', '2+, across object', '2−, across object', and '3, across object'. The '2+, across' and '2−, across' levels were averaged to generate a single measure of performance, '2, across', for the case where probes were two circles removed from cued targets. The mean percent-correct probe discriminations for the four resulting conditions are plotted in Fig. 4. Note that, since the discrimination was a 2-AFC, chance performance was 50%.

Inspection of Fig. 4 reveals that performance in the '3, across-object' condition was surprisingly high, and the standard error was also high in this condition. Performance in the '3, across-object' condition appears to have been anomalous, perhaps because participants sometimes failed to distinguish between the actual cue direction and the opposite direction. This condition was therefore omitted from the analyses. In a one-way repeated-measures ANOVA conducted on the three remaining conditions, there was a significant effect of relative location ($F(2,10) = 6.72$, $p < 0.014$). However, an ANOVA comparing the '1, across-object' and '2, across-object' conditions showed absolutely no evidence for an effect of spatial separation. On the other hand, there was a reliable benefit for the '1, within-object' condition relative to the '1, across-object' condition ($F(1,5) = 15.88$, $p < 0.01$).

2.3. Discussion

We found a significant effect of whether the probe fell (i) in the same object as the cued target ('1, within object') or (ii) an equal distance away in a different object ('1, across object'). Thus perceptual grouping affected selection; apparently, attention spread, on the basis of grouping, from the cued-target location to the probe location within the same object (see also Bekkering & Pratt, 2004; Egly et al., 1994).

In contrast to this evidence for object-based effects, there was no indication that performance fell off with increasing spatial separation between the critical stimuli. Indeed, what little trend there was in the data was for performance to increase with increasing separation—largely because the '3, across object' condition produced unexpectedly good performance. In this condition, the cued target and probe were situated directly opposite each other, on opposite sides of fixation. We attribute the unexpectedly good performance in this condition to occasional misinterpretations of the cue (using the oriented cue to shift attention in the opposite direction), although it could also be based on a higher-level parsing of the display involving symmetry (see Deubel et al., 1998). Given the uncertainty surrounding this condition, it was excluded from further analyses.

3. Experiment 2: Movement to a spatially cued location

With the advantage for the '1, within object' over the '1, across object' condition in Experiment 1, we established that our displays supported grouping based on connectedness, common movement and/or colour. In Experiment 2, we used the same displays to test whether grouping can modulate the coupling between movement and attention (cf. Deubel et al., 1998). This was achieved by making the primary task a pointing movement to the cued location rather than the discrimination of a target in that location. If attention is influenced by grouping even when a movement is being made to just a part of an object, then probe discrimination should be better in the '1, within object' condition (when the probe occurred in the same object as the pointing movement, but one circle removed from the movement) than in the '1, across object' condition (when the probe occurred in a different object from the pointing movement, again one circle removed). On the other hand, if the pointing movement over-rules any effect of grouping on selection, probe discrimination might not differ in these two conditions.

The only change made to the displays in Experiment 2 was that cued targets were replaced with distractors (see frame 4 of Fig. 3). This had the advantage that probes could occur in the cued location, as in Deubel et al. (1998). Deubel et al. showed that probe discrimination was uniquely good when the probe fell in the same location as a pointing movement (the '0, within object' condition). It was important to replicate their finding using our displays, given that a weak or absent coupling between attention and action might also minimise any difference between the '1, within object' and '1, across object' conditions. It was an empirical issue whether our displays would support a replication, given that pointing movements to our displays were all of the same amplitude, and differed only in their angular direction. In contrast, pointing movements in the study of Deubel et al. differed in their amplitude. It is possible that it is more difficult to program movements that also differ in their amplitude, and that increased difficulty of programming generates stronger coupling between action and attention.

3.1. Method

3.1.1. Participants

Six participants took part, with ages ranging from 17 to 24 years. Four were male and two female. All of the participants were right-handed and had normal or corrected-to-normal vision and motor behaviour. All but one (who was one of the authors of the study, SL) were naïve with respect to the aim of the study.

3.1.2. Experimental setup

The experimental setup was the same as in Experiment 1, except that the stimulus-presentation PC was interfaced with a second PC running Proreflex motion-capture software and connected to three infrared (IR) cameras. The motion-capture system tracked the position in 3D space of an IR-reflective ball attached to the nail of the pointing finger, sampling at a frequency of 200 Hz. The stimulus-presentation system triggered the cameras (through the parallel port) and provided auditory and visual feedback about pointing movements (see below), as appropriate to the stimulus presentation and the participant's responses.

Participants viewed displays projected onto a base plane, exactly as in Experiment 1. In this and the subsequent experiment, however, they rested the index finger of their dominant (right) hand at the centre of the base plane, which coincided with the centre of the projected image and the fixation point. Given that the pointing plane was viewed in semi-darkened conditions through the one-way mirror (see Fig. 2), the pointing finger could be moved unseen on the plane. A light-emitting diode (LED) was attached to the nail of the pointing finger, just below the IR-reflective ball. When the LED was switched on, the finger was visible through the one-way mirror. By switching the LED on before and after pointing movements, it was possible to give feedback to the participant about the position of their pointing finger at the start and end of each movement.

Feedback about the speed of onset of pointing movements was provided using a switch located in the base-board, at the perceived centre of the projected image. The switch was a metal washer with a diameter of 10 mm that exactly matched the perceived diameter and spatial location of the grey fixation spot at the centre of each display. The washer was cut into two to break the electrical circuit into which it was connected. When the participant rested their finger on the washer, the circuit was made. By recording the time when the movement cue was first presented, and the time when the circuit was broken (i.e. the time when the finger first moved off the washer in the direction indicated by the cue), on-line feedback could be provided to the participant concerning the speed of initiation of movement.

The pointing arm was supported at the elbow with an adjustable cushion so that most of the movement was made with the hand and the finger, rather than the arm. As in Experiment 1, the index finger and middle finger of the non-pointing (left) hand were rested on the two buttons of the discrimination-response box.

3.1.3. Stimuli

Displays were exactly as in Experiment 1, except that no 'cued target' stimulus occurred in the cued location. Instead, another distractor stimulus ('ㄹ' or 'S') appeared there (see frame 4 of Fig. 3).

3.1.4. Procedure

At the beginning of each trial, the LED on the participant's pointing finger was illuminated for 1.5 s. The participant placed their pointing finger on the switch at the centre of the baseboard and fixated their eyes on the grey fixation circle perceived as occupying the same location as the switch. At the same time as the LED was lit, the three objects started to pulsate around their centres of gravity. As in Experiment 1, the pulsating ceased after 3 s (1.5 s after the LED had been extinguished) and the display was then static for 200 ms (see frames 1 and 2 of Fig. 3). Next, the cue and the pre-stimulus masks were presented (see frame 3 in Fig. 3). The cue signalled a pointing movement to the centre of the circle it pointed to. For example, the movement cue in Fig. 3 cued a movement to the centre of the circle at 3-o'clock. 100 ms after the presentation of the cue, the pre-stimulus masks were replaced, any one of them by a probe stimulus ('ㅌ' or '∃') and the remaining five by distractor stimuli ('ㄹ' or 'S'; see frame 4 in Fig. 3). The probe and distractor stimuli remained visible for 140 ms, after which they were replaced with post-stimulus masks (see frame 5 in Fig. 3).

Participants were instructed to allocate the movement task priority over the discrimination task, and to make every movement as quickly and as accurately as possible. They were told that they should not correct any inaccurate movements after the first landing of the finger, and that under no circumstances should movements simply involve dragging the finger over the base platform. This increased the likelihood that movements had to be pre-programmed. (Deubel & Schneider, 1996, have presented evidence that any coupling between movement and attention occurs at the stage when a movement is being programmed.)

On average, movements took more than 400 ms to initiate. This meant that post-stimulus masks had invariably been presented by the time that movement started. One second after the initiation of movements, auditory feedback was given concerning movement-initiation time. This consisted of a high or a low beep generated directly off the motherboard: a low beep signalled too slow an onset if movement initiation took more than 500 ms; otherwise, a high beep signalled that the movement had been initiated sufficiently fast. Coincident with the auditory feedback, we also provided visual feedback concerning pointing accuracy by illuminating the LED on the pointing finger for 1 s. Subsequently, a single unspeeded probe-discrimination response was required. The discrimination response consisted in pressing the left-hand button of the button-box for 'ㅌ', or the right-hand button for '∃'.

After the discrimination response, the post-stimulus masks and the movement cue were removed, leaving just the three objects and the central circle for 2.5 s (see frame 6 in Fig. 3). Then the LED was lit again for 1.5 s, so that the finger could be returned to the starting position. At the same time that the LED was lit, the stimulus objects started to pulsate again and the next trial started.

Trials were presented in blocks of 72 trials that took approximately 15 min to complete. The experiment consisted of 9 blocks of 72 trials. These experimental blocks were completed in either two or three sessions on different days.

Before completing the experimental blocks, all participants had to attain a criterion level of performance in a practice session. The practice session started with discrimination-only trials. Participants had to achieve 65% correct probe discriminations within a block, before moving on to perform pointing-only trials. Pointing-only was continued until 80% of the movements within a block were initiated in less than 500 ms and 100% of the movements were accurate (landing within the white circle defining the movement location) and smooth (without sharp discontinuities in velocity). To ensure that this was the case the experimenter observed movements closely and provided verbal feedback. In the final part of the practice session, participants performed both pointing and discrimination, just as in the dual-task blocks of the experiment proper. The practice session ended when a block of trials was completed in which movements met the same requirements as in the pointing-alone task, and in which 60% of the discriminations were correct.

3.1.5. Design

There were two independent variables, the location of the pointing movement (1 of 6 locations) and the location of the probe relative to the pointing movement (1 of 6 *relative* locations: (1) same circle, within the same object—'0, within object'; (2) one circle away, within the same object—'1, within object'; (3) one circle away, in a different object—'1, across object'; (4) two circles away in a clockwise direction, in a different object—'2+, across object'; (5) two circles away in an anti-clockwise direction, in a different object—'2−, across object'; and (6) three circles away, in a different object—'3, across-object'). Each block of 72 trials contained 2 trials for each of the 36 combinations of 6 pointing-target locations and 6 relative probe locations. The ordering of the different trial-types was randomly determined within each block. The dependent variable was probe discrimination, measured as a function of the relative location of the pointing movement and the probe, and averaged across the six pointing-movement locations (see below).

3.2. Results

Only those trials on which the participant made fast and accurate movements were used in the discrimination analysis. A movement was judged to be sufficiently fast when the finger left the electronic switch less than 600 ms after the presentation of the movement cue.[2] The average movement initiation time (RT) was 423 ms. Movement duration (MT) and accuracy were gauged by analysing the output of the movement tracking software. The movement record was searched for the time at which the transgression and subgression of a vectorial velocity threshold of 10 mm/s occurred. The time and location of the launching and the landing of each movement were then calculated from linear regressions of the velocity-on-time function in a 200-ms time window around these transgression and subgression times, respectively: they were defined as the time and location

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[2] The rationale for excluding trials with movement initiation times longer than 600 ms was that, at longer times, it was impossible to exclude the possibility that the observer allocated their processing resources to the discrimination task before they prepared the movement.

corresponding to the 10 mm/s-point on the corresponding regressed line. By differencing the time of launching of the movement from the time of landing, we were able to calculate the movement duration (MT). The average MT was 285 ms. Neither the movement duration (MT) nor the RT to initiate the movement varied with the relative locations of the movement and the probe (see analyses at the end of this section).

The mid-point of the display was defined operationally on each trial (in accordance with the perception of the observer), by equating it with the location from which the movement on that trial was launched (as defined above). By this means, the impact of any variation in the placement of the LED on the pointing finger and/or in the angle from which the LED was viewed was minimised. The target location for the pointing movement was defined operationally on each trial, by combining the displacement in x, y-coordinates between the true mid-point of the display and the true target location for the movement with the x, y-coordinates of the operational mid-point (see above). The accuracy of the movement was then gauged by measuring the euclidian distance between this operational target location and the actual landing location. If this distance was more than 19.25 mm (half the distance between adjacent movement-target locations), the movement was classed as inaccurate and the trial was discarded from the discrimination analysis. Across participants, only 0.03% of the trials had to be discarded; almost all movements fell within the perimeter of the appropriate white circles. Accuracy did not differ as a function of where the probe fell in relation to the pointing movement.

For trials on which movements were sufficiently fast and accurate, the percent-correct probe discrimination was broken down as a function of the location of the probe *relative to* that of the pointing movement, collapsed across the six possible movement locations. This generated six different measurements, one for each of the six different levels of the relative-location factor: '0, within object', '1, within object', '1, across object', '2+, across object', '2−, across object', and '3, across object' (see Section 3.1.5). The '2+, across' and '2−, across' levels were averaged to generate a single measure of performance, '2, across', for the case where probes were two circles removed from the target locations of pointing movements. The group-mean percent-correct discrimination data for the resulting five relative-location levels are plotted in Fig. 5. Note that the '3, across-object' condition again appears anomalous.

A one-way repeated-measures ANOVA comparing the critical different levels of the relative-location factor (omitting the problematic '3, across-object' condition; see Sections 2.2 and 2.3) demonstrated a significant effect on probe discrimination of relative location ($F(3,15) = 3.53$, $p < 0.041$). There was no effect on probe discrimination of spatial separation between the movement and the probe, when the '1, across-object' and '2, across-object' conditions were compared. However, an ANOVA comparing the '0, within-object' condition' (in which the movement end-point and probe were in the *same* location) with the average of the other three conditions ('1, within-object', '1, across-object' and '2, across-object', in all of which the movement end-point and probe were in *different* locations) showed that probe discrimination was better when movement and perception converged on the same spatial location ($F(1,5) = 6.09$, $p < 0.057$). Finally, an ANOVA comparing the '1, within-object' condition with the '1, across-object' condition showed that there was no evidence whatsoever for object-based effects on probe discrimination ($F(1,5) = 0.01$, $p < 0.912$).

Analyses, identical to those reported above on probe discrimination, were conducted on movement RT and MT, to exclude the possibility that the relative locations of movements and probes in any way affected movement characteristics. Taking movement RT first, an ANOVA

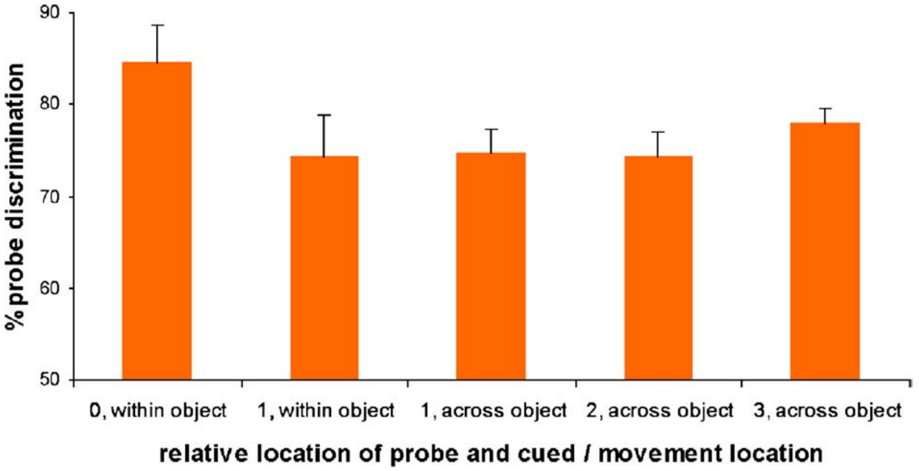

Fig. 5. Experiment 2: Group-mean percent-correct probe discrimination for the five relative-location conditions. Bars indicate standard errors.

comparing the '0, within-object' condition with the average of the other three conditions, showed that movement RT was unaffected by whether the movement was initiated to a location containing the probe or not (mean movement RT was 426 ms when movement and probe locations overlapped, and 422 ms when they did not; $F(1,5) = 2.23$, $p < 0.195$). An ANOVA comparing movement RTs for the '1, within-object' condition and the '1, across-object' condition showed that there was no evidence whatsoever for object-based effects on movement RT (mean movement RT was 421 ms when movement and probe locations were in the same object, and 421 ms when they were not; $F(1,5) = 0.07$, $p < 0.800$).

Moving on now to movement duration (MT), an ANOVA comparing the '0, within-object' condition' with the average of the other three conditions, showed that MT was unaffected by whether the movement was initiated to a location containing the probe or not (mean MT was 287 ms when movement and probe locations overlapped, and 285 ms when they did not; $F(1,5) = 0.76$, $p < 0.423$). An ANOVA comparing MTs for the '1, within-object' condition and the '1, across-object' condition showed that there was no evidence whatsoever for object-based effects on MT (mean MT was 286 ms when movement and probe locations were in the same object, and 282 ms when they were not; $F(1,5) = 1.63$, $p < 0.258$).

3.3. Discussion

Our probe-discrimination data in the '0, within-object' condition demonstrate that discrimination improved when the probe fell at the location of the planned pointing movement. Given that movement characteristics (both RT and MT) were insensitive to the relative locations of movements and probes, our data are compatible with attention being preferentially allocated to the location where a pointing movement is being prepared (although see Section 4.3). The results extend the findings of Deubel et al. (1998) to the case where pointing movements are of fixed amplitudes but varying angular direction.

However, over and above this, we found no effect on discrimination of whether the probe fell (i) in the same object as the cued end-point of the movement ('1, within object') or (ii) an equal distance away in a different object to the end-point ('1, across object'). This failure to find an effect of object-based coding on probe discrimination contrasts with our evidence from the dual-discrimination task in Experiment 1. In the latter case, the probe was reported better when it fell (i) in the same object as a cued target ('1, within object') than (ii) an equal distance away but in a different object ('1, across object'). In Experiment 2, attention apparently went to the intended end-point of the pointing movement and did not spread, on the basis of grouping, to the other location within the same object. Thus, preparing the pointing response seemed to over-rule effects of perceptual grouping on selection. This result is similar to the finding in the study of Fischer and Hoellen (2004), that showed only effects of spatial distance on cueing effects when participants made manual pointing responses to targets, though our study involved the effects of a programmed movement to one (cued) location on the perception of a probe at another location.

However, before we conclude that pointing per se was responsible for the lack of object-based processing in Experiment 2, we briefly consider other differences between Experiments 1 and 2 that could feasibly have explained their different results: (1) a potential difference in the extent to which attention was focused at the cued location, depending on the attentional requirements of the primary task; (2) a difference in overall task difficulty (probe detection performance was overall better in Experiment 2 than 1), and (3) possible effects of greater dual-task load, in Experiment 2. It is unclear in what direction the first factor might impact upon the data. An anonymous referee suggested that if attention was less focused in Experiment 2 (where visual discrimination was required in the cued location on only 1 in 6 trials) this might explain the absence of an object-based effect here. Goldsmith and Yeari (2003), on the other hand, provided evidence that object-based effects are obtained under conditions that encourage the spread of attention and are attenuated under conditions that encourage focused attention. To test whether our data provided any evidence for a relationship between attentional focus and object-based processing, we performed an individual-differences analysis on the six participants who took part in Experiment 2. The question was whether there was any relationship between the extent to which a participant focused their attention on the cued location (indexed by the difference between probe discrimination in the cued location and in the average of all six display locations) and the amount of object-based processing they showed (indexed by the difference between probe discrimination in the '1, within object' and '1, across object' conditions). There was no evidence for any relationship (average probe detection in the '1, within object' and '1, across object' conditions respectively was 75.5% and 76.8% for the three participants who were most focused on the cued location, and 73.2% and 72.6% for the three participants who were least focused).

Similarly, to test whether the easier probe discrimination in Experiment 2 could account for the lack of evidence for object-based processing, we split our participants into two different groups who showed the highest and lowest average probe discrimination. If anything, those participants who performed best showed more evidence for object-based processing (average probe detection in the '1, within object' and '1, across object' conditions was 82.2% and 77.5% respectively for the three participants who performed best at probe discrimination, and 66.5% and 71.9% for the three participants who performed worst). Thus the higher overall probe discrimination in Experiment 2 compared to 1 should have improved our chances of demonstrating object-based processing.

A third possibility raised by another anonymous referee is that differences reflect a higher dual-task load in Experiment 2 (although the higher probe discrimination in Experiment 2 seems difficult to reconcile with this suggestion). According to this third possibility, the load of performing a pointing movement in addition to the visual-discrimination task reduced the resources available, eliminating any effects of object-based coding on how attention spread across the display. Against this, in Linnell and Humphreys (submitted for publication) we have reported data on the effects on visual attention when a grasp action is made to a given stimulus. In contrast to the present experiment on pointing, our study on grasping revealed an object-based effect on visual selection: there was better discrimination of visual probes that fell in the same object as the programmed grasp action compared with probes that fell the same distance away from the end point of the action, but in a different object. Since, if anything, grasping is a more difficult motor task than pointing, it is difficult to explain why evidence of object-based coding emerged in grasping but not in pointing, if dual-task load reduced object-based effects. Rather, the data are consistent with the contrasting actions of pointing and grasping having different effects on the allocation of attention (see also Bekkering & Neggers, 2002; Fischer & Hoellen, 2004; Humphreys & Riddoch, 2001). We return to this point in Section 5.

In the absence of any supporting evidence for the importance of these confounding factors, we conclude that pointing was the critical factor that generated the qualitative difference in the outcomes of Experiments 1 and 2. There remain alternative explanations for why pointing (to an object part) eliminates object-based processing. One possibility is that, when a pointing movement is made, spatial processes in selection are emphasised at the expense of object-based selection. In this case, there is enhanced perception only at the pointed-to location and there is no influence of grouping on the perception of probes appearing at other locations within the pointed-to object (Fischer & Hoellen, 2004). Alternatively, pointing to a part of an object may alter the representation being attended. Objects can be parsed at several hierarchical levels of structure (see, e.g., Marr, 1982) and the effective level may be dictated by task demands or attentional set (e.g., Humphreys & Riddoch, 1994, 1995). Requiring the participant to point to a specific part of each 'object' may actually have caused participants to parse these *parts* as objects. Whatever is the case, the data do demonstrate that the impact of grouping on perceptual report from displays was altered by the introduction of the pointing task in Experiment 2.

In Experiment 3, we sought to assess whether attention can ever be influenced by processes that group parts into an object when a pointing action is made to a part. We used the same displays as in earlier experiments, but changed the task demands. When participants were cued to one circle (or part) within an object, they had to make a pointing movement to an adjacent circle (or part) either in the same, or in a different, object. In this case, participants may be forced to attend to entire objects to programme their movements. Is probe discrimination in the within-object ('1, within object') condition then better than in the across-object ('1, across object') condition, even though pointing to object parts is still involved?

4. Experiment 3: Moving to a location cued relative to an object

In Experiment 3, we used the 'two-circle' objects of earlier experiments, but changed the significance of the cue: while we explicitly cued participants to one circle (as before), we now required them to make a pointing response to an adjacent circle. In different blocks with different task demands, the pointing movement was either to an adjacent circle within the same object, or to an adjacent circle in a different object. The spatial relations between the cued location and the pointed-to location varied across the different trials of a block (on half the trials the pointed-to location was clockwise of the cued location, and on the other half it was counter-clockwise of the cued location). Across trials and blocks then, the end-point of any pointing movement could only be determined by reference to the grouping of the circles to form objects. To increase the perceptual salience of objects, the three objects within each display were given different colours. Under these conditions, we tested whether there may be a greater spread of attention within objects than between objects (as in Experiment 1), even though pointing responses were made to parts of objects (as in Experiment 2).

Because the cued location no longer coincided with the movement location, we could calculate probe discrimination as a function of the relative location of the probe and (i) the cued location, and (ii) the location of the pointing movement. As in previous experiments, the focus was on object-based effects, diagnosed through a comparison of probe discrimination in the '1, within-object' and '1, across-object' conditions. However, here we analysed within- and across-object conditions for probe locations coded relative to *both* (i) cued locations and (ii) moved-to locations. This was done by pooling the data from the 'move within object' and 'move across object' tasks (see Fig. 6).

Comparisons of performance relative to the cued location can inform us about probe discrimination in the '1, within object' and '1, across object' cue-relative conditions as a function of whether or not the probe appears at the location where the pointing response is made (see Fig. 6a). Comparisons of performance relative to the location of the pointing response can inform us about probe discrimination in the '1, within object' and '1, across object' movement-relative conditions as a function of whether or not the probe appears at the cued location (see Fig. 6b). In the first comparisons relative to the cued location (Fig. 6a), we can ask (i) whether discrimination performance is enhanced only when the probe falls at the same location as the pointing response (see Experiment 2), or (ii) whether performance is also modulated by whether the probe falls in the same object as the cue. In the second set of comparisons relative to the location of the pointing response (Fig. 6b), we can ask whether performance is affected by (iii) whether or not the probe falls at the location indicated by the visual cue, and (iv) whether or not the probe falls in the same object as the movement. Prior studies have not separated effects on attention of visual cueing from effects due to the location of a programmed action.

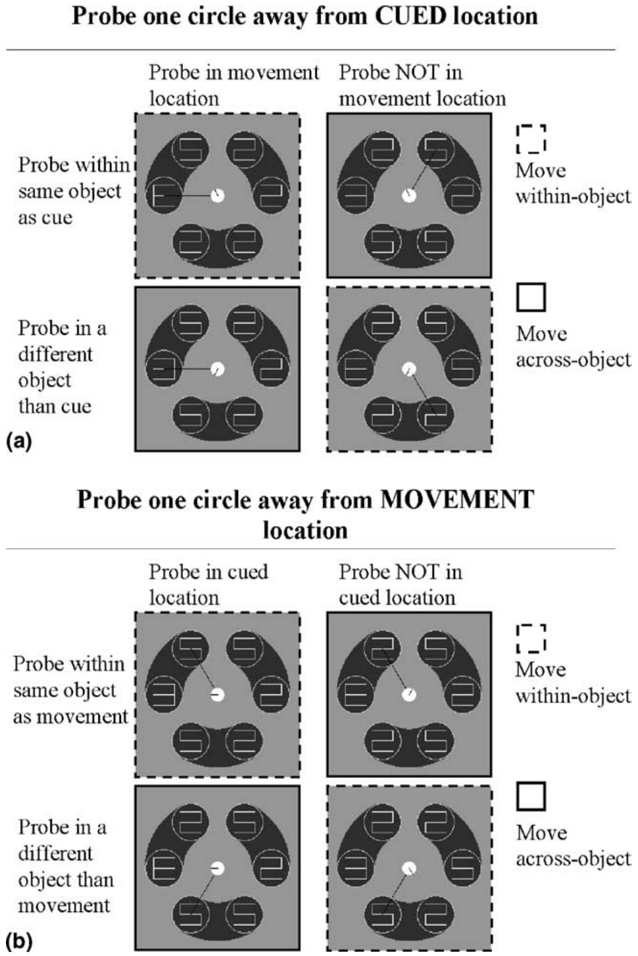

Fig. 6. The critical conditions presented in Experiment 3. In (a) we illustrate the conditions where the probe was presented one circle away from the location indicated by the visual cue. Displays are separated according to whether or not the probe appeared at the end-location of the pointing movement (columns 1 and 2 respectively) and whether or not the probe appeared within the same object as the cue (rows 1 and 2 respectively). Displays given a hatched surround are drawn from the task where participants were asked to move to the location adjacent to the cued location but in the same object ('move within-object' task); displays given a continuous surround are drawn from the condition where participants moved to the location adjacent to the cued location in a different object ('move across-objects' task). The black line in the central circle in each display is the visual cue; another black line (absent from experimental displays) represents the intended trajectory of the pointing movement. In (b) we illustrate the conditions where the probe was presented one circle away from the end-point of the pointing movement. Displays are separated according to whether or not the probe appeared in the cued location (columns 1 and 2 respectively) and whether or not the probe appeared within the same object as the end-point of the movement (rows 1 and 2 respectively).

4.1. Method

4.1.1. Participants

Four participants took part in the experiment. Three had already participated in Experiment 2. Their ages ranged from 17 to 24 years. Three of the participants were male and one female. All of the participants were right-handed and had normal or corrected-to-normal vision and motor behaviour. All of the participants were naïve with respect to the aim of the study.

4.1.2. Stimuli

The stimuli were the same as in Experiment 2, except that the three elongated 'objects' were now different colours: one object was always red, one always green, and one always blue. These colours were equated for luminance with each other using flicker photometry. Their luminance was 3 cd/m^2 (as in Experiments 1 and 2).

4.1.3. Procedure

The procedure was exactly as in Experiment 2, except that whichever circle the movement cue pointed to, the participant had to point to the adjacent circle that fell either (in 'within-object' task blocks) within the same object or (in 'across-object' task blocks) in a different object. Task instructions were more complex to process than in earlier experiments, and movement initiation times (RTs) were correspondingly slower. Therefore, the auditory feedback that was given regarding movement initiation times signalled a satisfactorily speedy onset whenever movements were initiated in less than 600 ms (cf. the 500-ms cut-off which was operated in Experiment 2).

As in Experiment 2, the conditions were presented in blocks of 72 trials, and the experiment consisted of 9 'move-within-object' blocks and 9 'move-across-object' blocks. The two groups of 9 blocks were performed in counter-balanced order across participants. Practice sessions preceded each group of 9 blocks. The movement-initiation time used as a criterion was in each case 600 ms, reflecting the increased processing demands of the task (cf. Experiment 2).

4.1.4. Design

This was the same as in Experiment 2, except that probe discrimination was calculated as a function of the relative location of the probe and *both* (i) the cue, and (ii) the movement location.

4.2. Results

The data on probe discrimination were analysed only when the participant made fast and accurate movements. A movement was judged to be sufficiently fast when the finger left the electronic switch less than 700 ms after the presentation of the movement cue.[3] On average, this movement initiation time (RT) was 529 ms, while movement duration (MT) was 306 ms. Movement accuracy was gauged as in Experiment 2. For all trials on which movements were sufficiently fast and accurate, pooled from across the 18 test blocks (9 'move within objects' and 9 'move across objects'), the percent-correct probe discrimination was calculated separately for four probe locations *relative to the cue* (see Fig. 6a), and for four probe locations *relative to the pointing movement* (see Fig. 6b). To check that movement parameters were unaffected by relative probe locations, both movement initiation time (RT) and duration (MT) were also calculated separately for four probe locations *relative to the cue*, and for four probe locations *relative to the pointing movement* (see below).

4.2.1. Probe discrimination and movement RT and MT for probe locations defined relative to the cued location

The four probe locations relative to the cue were: '1, within object, movement location', '1, across object, movement location', '1, within object, *not* movement location', and '1, across object, *not* movement location' (see Fig. 6a).

The group-mean percent-correct probe-discrimination data for these four conditions are plotted in Fig. 7.

A two-way repeated-measures ANOVA was conducted on the probe-discrimination data with the factors being Object ('1, within-object' vs. '1, across-object') and Movement ('movement location' vs. 'not movement location'). There was only a significant effect of Movement ($F(1,3) = 16.52$, $p < 0.027$) on probe discrimination; the effect of Object and the Object × Movement interaction failed to approach significance ($F(1,3) = 1.95$, $p < 0.257$, and $F(1,3) = 0.04$, $p < 0.863$, respectively). Probe discrimination was increased when the probe fell at the location of the pointing response, but this effect was not modulated by whether the probe fell in the same object as the cue.

An identical two-way repeated-measures ANOVA was conducted on the movement RT data ('1, within object, movement location'—539 ms; '1, across object, movement location'—520 ms; '1, within object, *not* movement location'—516 ms; and '1, across object, *not* movement location'—537 ms). There was a just significant interaction between Object and Movement ($F(1,3) = 9.47$, $p < 0.054$) on movement RT; the main effects of Object and of Movement both failed to approach significance ($F(1,3) = 0.16$, $p < 0.716$, and $F(1,3) = 4.20$, $p < 0.133$, respectively). The interaction did not arise because relative probe location influenced movement parameters; rather, it is explained by the fact that movement RT was about 20 ms faster in the 'move across objects' task (that generated the '1, within object, movement location' and '1, across object, *not* movement location' data) than in the 'move within objects' task (that generated the '1, across object, movement location' and '1, within object, *not* movement location' data).

Finally, an identical two-way repeated-measures ANOVA was conducted on the MT data ('1, within object, movement location'—295 ms; '1, across object, movement location'—314 ms; '1, within object, *not* movement location'—316 ms; and '1, across object, *not* movement location'—304 ms). The interaction between Object and Movement failed to reach significance for MT ($F(1,3) = 3.28$, $p < 0.168$), even though MTs for the 'move within objects' task were some 15 ms faster than those for the 'move across objects' one; the main effects of Object and of Movement both again failed to approach significance ($F(1,3) = 0.68$, $p < 0.471$, and $F(1,3) = 1.58$, $p < 0.298$, respectively).

4.2.2. Probe discrimination and movement RT and MT for probe locations defined relative to the movement location

The four probe locations relative to the movement location were: '1, within object, *cued* location', '1, across object, *cued* location', '1, within object, *not cued* location', and '1, across object, *not cued* location' (see Fig. 6b).

The group-mean percent-correct probe discrimination data for these four conditions are plotted in Fig. 8.

A two-way repeated-measures ANOVA was conducted on probe discrimination with the factors being Object ('1, within-object' vs. '1, across-object') and Cue ('cued location' vs. 'not cued location'). There was no

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[3] The 700-ms threshold was longer than the 600-ms one used in earlier experiments because task instructions were more complex to process in Experiment 3 and movement initiation times were correspondingly slower.

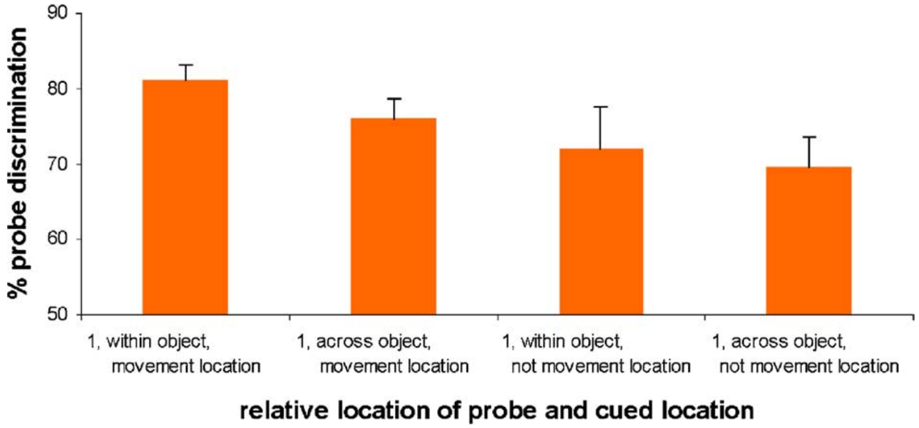

Fig. 7. Experiment 3: Group-mean percent-correct probe discriminations in Experiment 3 for conditions where the probe was one circle away from the cued location.

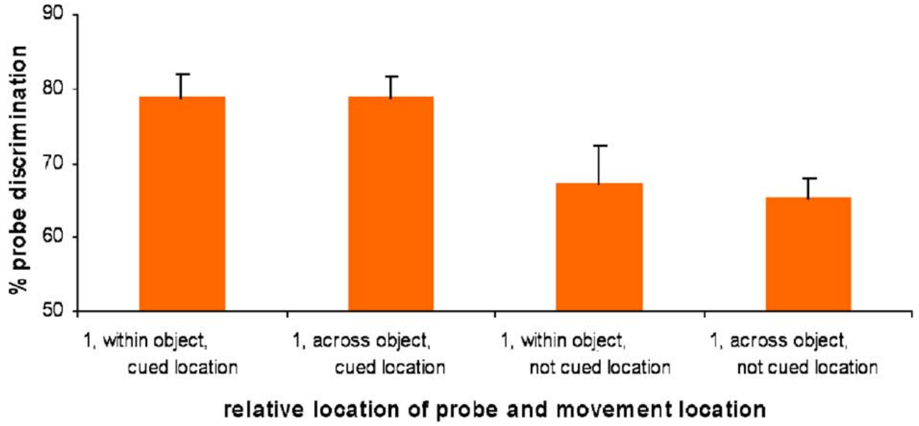

Fig. 8. Experiment 3: Group-mean percent-correct probe discriminations in Experiment 3 for conditions where the probe was one circle away from the end-point of the pointing movement.

effect of Object ($F < 1.0$), a marginal effect of Cue ($F(1,3) = 8.13$, $p < 0.07$), and no interaction ($F < 1.0$) on probe discrimination. There was a trend for probe discrimination to be improved when the probe fell at the location indicated by the visual cue, but this was not affected by whether the probe appeared in the same or in a different object to the end-point of the movement.

An identical two-way repeated-measures ANOVA was conducted on the movement RT data (‘1, within object, cue location’—539 ms; ‘1, across object, cue location’—523 ms; ‘1, within object, *not* cue location’—521 ms; and ‘1, across object, *not* cue location’—539 ms). The interaction between Object and Cue failed to reach significance ($F(1,3) = 3.98$, $p < 0.140$) on movement RT, as did the main effects of Object and of Cue on movement RT ($F(1,3) = 0.15$, $p < 0.727$, and $F(1,3) = 0.68$, $p < 0.470$, respectively).

Finally, an identical two-way repeated-measures ANOVA was conducted on the MT data (‘1, within object, cue location’—301 ms; ‘1, across object, cue location’—317 ms; ‘1, within object, *not* cue location’—304 ms; and ‘1, across object, *not* cue location’—294 ms). The interaction between Object and Cue failed to reach significance ($F(1,3) = 1.10$, $p < 0.372$) on MT, as did the main effects of Object and of Cue on MT ($F(1,3) = 0.69$, $p < 0.467$, and $F(1,3) = 5.80$, $p < 0.095$, respectively).

4.3. Discussion

The data support the results of Experiment 2 and show strong effects on probe discrimination (but not on movement parameters) of whether a probe falls at the location of a movement, and no influence on probe discrimination (or on movement parameters) of whether the probe is within the same or within a different object relative to either the movement location or the cue. There was also a moderate effect on probe discrimination of whether the probe appeared at the location indicated by the visual cue.

Let us consider first the results coded in relation to the position of the cue (Fig. 6a). Here probe discrimination was enhanced when the probe appeared at the location to where the pointing response was programmed. However, the magnitude of this enhancement did not change as a function of whether the probe fell in the same object as the cue or whether it fell in a different object. Similarly, when we turn to consider probe discrimination coded according to the relative positions of the probe and the movement (Fig. 6b), we find no effect of whether or not the probe fell in the same object as the location of the movement. The failure to find any object-based modulation of performance here contrasts with the positive effects observed in Experiment 1, particularly given that objects were relevant to performance in Experiment 3, but not in Experiment 1. We conclude that, although grouping between the parts was sufficient to establish an object-based effect (Experiment 1), it was overruled under conditions of movement. When a movement was programmed either (i) there was an enhanced influence of spatial attention, reducing object-based effects, or (ii) the stimuli were re-coded so that the relevant part became the 'object' directing both action and selection.

In addition to the effects of movement, we did find some (moderate) influence on probe discrimination of the location of the visual cue (even though this related to a location different to the end point of the movement response). This is interesting since it suggests some effects of the visual cue separate from the influence of movement. As we have noted, in previous studies (e.g., Deubel et al., 1998) participants have pointed to a cued location, so the effects of the visual cue have not been distinguished from those of the movement. In the present task, observers may have attended to the location of the cue first, in order to determine where they had to point.[4] The data suggest that there can be traceable effects of this initial allocation of attention even when a movement is subsequently programmed to another location. Thus, even if visual attention is captured by a subsequent movement, some residual effect of having attended to a separate cued location initially can be observed. Nevertheless, the movement that was always made to a display location seems to have eliminated any effects of object coding on performance.

The 'other side' of separating the effects of the visual cue and movement is that Experiment 3 demonstrates an effect of movement that is distinct from that of the visual cue. This indicates again that effects of movement on visual attention are not simply due to strong top-down modulation from a visual cue, under conditions of movement; there is a distinct and isolable effect of movement itself, that is also qualitatively different from the effect of cueing, in that it eliminates the influence of object coding on performance.

5. General discussion

We used a paradigm closely modelled on that developed by Deubel et al. (1998) to examine the coupling between action and attention. By using stimuli with multiple parts, we sought to assess the effects of object coding on any interactions between attention and action. When an action is made to a part of an object, is attention confined to that part or does it spread to other parts?

In Experiment 1, we provided evidence that effects of object-based selection could be found with the stimuli used in the study. When observers were required to discriminate a probe stimulus (without making any pointing response), discrimination of this probe was improved when it fell within another part of the same object as an initial cue (Egly et al., 1994). However, in Experiment 2, when the same cue directed a pointing movement to a part within an object, any object-based attentional effect on probe discrimination was eliminated. This finding was not a result of generally higher probe discrimination, less focused attention or reduced resources in Experiment 2 compared with 1. Those participants in Experiment 2 who performed best at probe discrimination or focused their attention least at the cued location tended to show more object-based processing. Also, in other work, we (Linnell & Humphreys, submitted for publication) have found object-based effects when a grasping rather than a pointing response was required. Since grasping is likely to be more demanding of resources than pointing, this rules out the argument that the load of the pointing task prevented attentional spread across objects. Evidence for object-based coupling between action and attention was absent even in Experiment 3, where pointing movements were made to locations adjacent to the cued location that could only be determined by an object-based parsing of the display. In both Experiments 2 and 3, however, there was increased discrimination of probes presented at the end-location of the pointing movement. In addition, in Experiment 3, there was (some) improvement in discrimination accuracy for probes at the location indicated by the visual cue. Improvements in movement and cued locations did not, however, generalise to other locations within the same object as either the movement *or* the cued location.

The data on the effects of movement on visual discrimination are consistent with those of Deubel et al. (1998) in suggesting that action is coupled with and affects visual attention. Indeed, in Experiment 3, we showed that there was an attentional benefit from programming a pointing response even when the response was made to a location different from the position indicated by a visual cue. In this instance, the effect of the movement cannot be attributed simply to increased effects of top-down cueing on discrimination (a possibility

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[4] This strategy might have been strengthened in participants who had performed Experiment 2 before Experiment 3.

also posed by Bonfiglioli, Duncan, Rorden, & Kennett, 2002). Instead the data indicate that preparation of a pointing response of fixed amplitude but varying direction (cf. Deubel et al., 1998) has a direct influence on visual processing, with processing being enhanced for stimuli at the location where the end point of the movement is programmed.

The data clearly show, however, that this enhancement did not spread to other locations within the same object. We have noted that there are at least two accounts that can be offered for this last result. One is that the programmed movement increases space-based attentional processes, which then have an increased influence relative to the influence of object-based attentional selection. This account holds that there are independent space- and object-based contributions to selection, perhaps both operating through feedback connections to early visual processing (e.g., Humphreys & Riddoch, 1993; Schneider, 1995). Within an interactive system sensitive to both space- and object-based attention, increasing the influence of one form of feedback may moderate effects of the other component. An account along these lines was offered by Fischer and Hoellen (2004) to explain their finding that object-based effects were minimized when participants made pointing actions to targets. Fischer and Hoellen found that object-based effects were re-introduced when a grasping response was made (similarly to Linnell & Humphreys, submitted for publication). These data suggest that either space- or object-based attention can be differentially weighted by the type of action being programmed: pointing enhances spatial selection, while grasping enhances object-based selection. This last conclusion also fits with data from Deubel and Schneider (2004) (see Schiegg, Deubel, & Schneider, 2003). These investigators found evidence for an object-based coupling between grasping and attention when they asked participants to grasp an elongated bar by positioning the thumb and forefinger of one hand at either end of the long axis of the bar. In this case, they showed that attention (1) was allocated to the two ends of the bar under the thumb and finger and (2) spread to the centre of the bar in an object-based fashion.

A somewhat different account of our data is that the requirement to programme a movement to one part of an object led to a recoding of the stimuli, so that just the critical part was represented as an object for action. On this view, the 'objects' formed by our visual system are flexible and can be coded across different spatial regions according to the task requirements. For example, while grasping may enhance whole object coding, pointing weights the target part as the perceptual object mediating performance. This fits with neuropsychological data indicating that there can be neglect of either whole scenes or parts of objects, depending on how stimuli are represented for the task (e.g., Humphreys & Riddoch, 1994, 1995). Note, however, that the two accounts are not mutually exclusive; there could be both enhanced activation of a location through spatial attention, along with a change in the underlying representation, based on task constraints.

In contrast to both our data and those of Fischer and Hoellen (2004), Bekkering and Pratt (2004) reported effects of object-coding on pointing responses to visual displays. Since we used an endogenous cue, and Bekkering and Pratt an exogenous cue, the contrasting results could reflect an interaction between action, attention and type of cue. On the other hand, Fischer and Hoellen used an exogenous cue too, but reported data that match ours. Moreover, as we have noted, participants in the Bekkering and Pratt study pointed at a target that followed an initial presentation of the cue. Hence, any movement could have been programmed on-line, following the presentation of the target, and without affecting visual attention. The time to initiate the movement (RT), though, could reflect the influence of visual attention on the time to detect the target in the first place, precipitating an effect of object-based selection on performance. In Experiment 2, here, the opposite condition held. Here the action was programmed to a cued location, and we examined the consequences on the allocation of visual attention to a probe presented during movement programming. In our Experiment 3, the pointing action was contingent on first coding an object in the display (with the action being made to an adjacent object part, either in the same or different object to the cued part), but we again measured the subsequent effects of action programming on attention. Even in this case, we found no effect of object-coding on performance, though a residual effect of the position of the visual cue was found. We conclude that programming an action to one object part eliminated object-based effects on selection.

Our present data, like those of Deubel et al. (1998), clearly indicate that movement has important implications for visual selection. Their particular contribution is to show that the programming of a pointing movement to one part of multi-part objects, and indeed the prevailing task set to point to parts of objects, can (i) cause attentional selection to switch from operating in an object-based to a space-based fashion, *and/or* (ii) cause object parts that are usually grouped and selected together to be represented as separate units for separate selection.

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