



## The interaction of attention and action: From seeing action to acting on perception

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We discuss evidence indicating that human visual attention is strongly modulated by the potential of objects for action. The possibility of action between multiple objects enables the objects to be attended as a single group, and the fit between individual objects in a group and the action that can be performed influences responses to group members. In addition, having a goal state to perform a particular action affects the stimuli that are selected along with the features and area of space that is attended. These effects of action may reflect statistical learning between environmental cues that are linked by action and/or the coupling between perception and action systems in the brain. The data support the argument that visual selection is a flexible process that emerges as a need to prioritize objects for action.

### Visual selection for action

The visual environments that we confront in everyday life typically contain multiple objects. However, having limited effector systems, we are constrained in the number of actions we can perform at any one time. To survive in such environments, we need to be able to select for action those stimuli that are of prime relevance to our behavioural goals. This reasoning led Allport (1987) to argue that visual selection is determined by our limited capacity for action. This argument is now almost taken as read in many accounts of visual attention and is expressed in different guises in models such as the integrative competition account of attention (Duncan, Humphreys, & Ward, 1997), the theory of visual attention (Bundesen, 1990; Bundesen, Habekost, & Kyllingsbaek, 2005), and the visual attention model (VAM; Schneider, 1995; Schneider & Deubel, 2002). Despite this argument being pervasive over the last 20 or so years, there has been surprisingly little consideration of how the specific constraints of action might modulate visual selection – for example, is there just a general constraint due to our having a limited number of effectors, or does action permeate attentional selection more deeply?

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Is attention tuned to the possibilities objects offer for action? Does the action we are set to perform influence what is selected and how different types of information are 'weighted' in the selection process? In this article, we review emerging evidence for the constraints of action infiltrating many aspects of selection.<sup>1</sup> We propose that our need to act upon the world not only imposes a general need for selection on our perceptual systems, but it directly mediates how selection operates. Attention is grounded in action.

We base our argument on work on three topics: (i) the effects of action properties of objects on visual selection; (ii) the effects of action relations on attention to members of a perceptual group; and (iii) the effects of action goals on visual selection.

### **Action properties of objects affect selection**

#### *Action relations between objects*

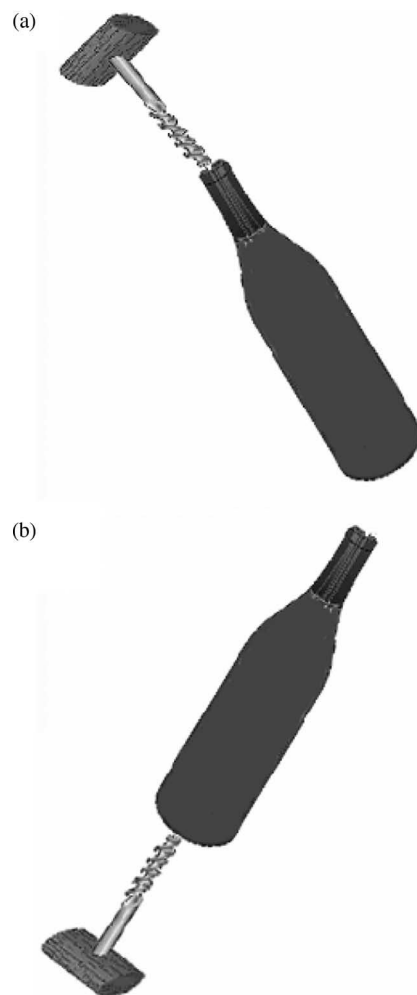
There is an abundance of evidence indicating that visual selection is determined by grouping between visual elements, with the grouping operating on the basis of the principles initially formulated by the Gestalt psychologists (e.g. Wertheimer, 1923; plus also other factors such as common region and uniform connectedness; see Humphreys, 1998; Palmer & Rock, 1994). Thus perceptual grouping between elements determines whether elements compete together for a response (Baylis & Driver, 1992), whether attention can be paid to an element within the group (Rensink & Enns, 1995), and even whether visual elements can be seen (see Humphreys, 1998, for a review). This last point is illustrated in a particularly dramatic fashion by studies of brain-lesioned patients who manifest the phenomenon of visual extinction. Patients showing visual extinction can respond to a single stimulus presented on the side of space contralateral to their lesion, but fail to detect the presence of the same item when another ipsilesional stimulus competes at the same time for attention (Karnath, 1988). Interestingly, extinction can be reduced if the contra- and ipsilesional stimuli group, in which case the patients are able to detect the presence of the contralesional stimulus. This effect has been demonstrated using a variety of factors including grouping by collinearity (Gilchrist, Humphreys, & Riddoch, 1996; Mattingley, Davis, & Driver, 1997), similarity of shape and surface luminance (Gilchrist *et al.*, 1996), common enclosure (Humphreys, 1998), and even whether the elements form a familiar shape (Kumada & Humphreys, 2001; Ward, Goodrich, & Driver, 1994). The processes of Gestalt grouping have typically been thought of as being integral to the way in which the visual 'module' glues together elements to form the objects that we subsequently recognize and act upon (cf. Marr, 1982). In this conceptualization, grouping reflects non-accidental properties of the environment (e.g. the presence of collinearity between two edges), which can be used to detect the presence of objects (e.g. Biederman, 1987).

We have used the phenomenon of recovery from extinction to explore whether visual elements are only grouped together through Gestalt factors or whether factors relating to the ways in which objects act together also constrain attention to the environment. That is, do the action relations between objects infiltrate the 'visual

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<sup>1</sup> We do not wish to overstate our claim and argue that all aspects of attention are based on action. For example, it is difficult to see any direct link to action when attention is allocated to words when reading. However in many circumstances we would argue that what is attended is modulated either by the possibilities for action offered by the stimuli or by the action intended by the observer.

module' to form part of the 'perceptual glue' determining how we perceive the world? In a first paper on this topic, Riddoch, Humphreys, Edwards, Baker, and Willson (2003) presented patients with pictures of separate objects which could interact together (e.g. a corkscrew and a bottle). The objects were either positioned as they would be seen when acting together (corkscrew about to enter the bottle) or they were positioned so that they could not be (easily) used together (e.g. corkscrew going into the bottle of the bottle; see Figure 1). In no case were there any Gestalt cues that would lead to an advantage for the objects depicted for action over those not depicted for action. The patients fixated on a location between the objects and they were asked to report what they could see. When the objects were placed in co-locations unrelated to action, the patients showed visual extinction - typically reporting the object appearing in their ipsilesional field and failing to detect the presence of the contralesional object. However, when the objects were positioned for action this extinction effect reduced



**Figure 1.** Example stimuli used by Riddoch *et al.* (2003) to examine the effects of action relations between objects on visual extinction. (a) Objects correctly positioned for action and (b) objects positioned incorrectly for action.

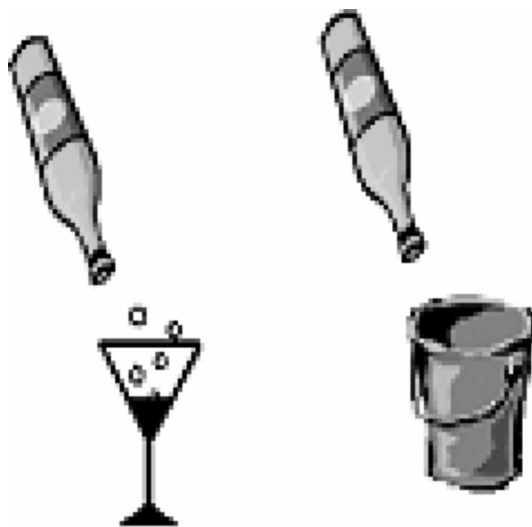
and the patients were better able to report the presence of both objects. The ability to attend to both objects was strongly influenced by whether the stimuli were shown interacting in a plausible way.

One way to think about these results is that the action relation between the objects enables the stimuli to be encoded as a single 'perceptual unit', so that both objects are selected together. This mitigates against the spatial bias in selection that produces extinction (Riddoch *et al.*, 2003). An alternative view is that an 'error detection' process is recruited when stimuli are positioned incorrectly for action, and this prolongs processing (e.g. a checking process may be initiated). Extinction then increases because processing takes longer than the limited exposures given. Rather than there being recovery from extinction due to the action relation between stimuli there is increased extinction where there is no action relation. Of course, to explain why any error detection process is recruited, we would still need to posit that action relations are coded by the patients. Hence our argument, that action relations are coded, still stands. On top of this, though, the 'error detection' account encounters difficulty with particular aspects of the data. We (Riddoch *et al.*, 2003) divided each pair of objects up on the basis of which object was 'active' during an action (the corkscrew, in Figure 1) and which was 'passive' (typically supported when the other object was being actively manipulated; the bottle, in our example). We then examined trials when extinction occurred (when only one object was detected), and noted which of the objects was reported. When the objects were not positioned for action the patients tended to identify just the object in their ipsilesional field and this occurred irrespective of whether it was the 'active' or 'passive' stimulus. This pattern changed when the objects were positioned for action. In this case, the patients tended to report the 'active' member of the pair (e.g. the corkscrew rather than the bottle) irrespective of whether it fell on the ipsi- or the contralesional side of space. This led to the intriguing situation where patients identified an 'active' object on the contralesional side (the corkscrew) and extinguished a 'passive' object on the ipsilesional side (the bottle) – the *opposite* to the normal result. It seems hard to explain how attention may be pulled into the contralesional field here, unless the action relation is coded initially, and it is difficult to explain why error detection would first check an active object when the stimuli are action related and not when the objects are unrelated to action. Instead of this, we suggest that action relations between objects influence how attention is allocated. Often attention will spread to both objects, reducing extinction. On some occasions, however, only one object may be attended. This particular object is affected by positioning the objects for action. The result also indicates that the effects of positioning the objects for action, on the report of two objects, were not due to patients guessing the identity of the contralesional object after having identified the ipsilesional one – since the effects of positioning were present even when only one object was detected.

Of course, when objects are positioned for action there are a host of factors that could influence attention – for example, in our original study the objects positioned for action were associatively related together, they fell in familiar co-locations, and the active object was either correctly or incorrectly positioned for action in its own right, irrespective of its relation to its partner. Which of these factors is critical? Riddoch *et al.* (2003) examined the effects of associative relation between objects by pairing together objects that were strongly associated but not used together in a common action (e.g. hammer and mallet, tin and can). There was no benefit to the patients from presenting associatively related pairs of objects compared with when the objects were unrelated (hammer and tin, mallet and can). Humphreys, Riddoch, and Fortt (2006) evaluated the

effects of placing the objects in familiar locations with respect to one another. They used objects that fall in regular co-locations, but are not part of a common action (e.g. the sun and a tree, since the sun normally appears above the tree). Again there was no evidence for recovery from extinction with such stimuli. Neither the presence of associative relations, nor of placing the objects in familiar co-locations, were sufficient to influence selection in the patients.

Riddoch *et al.* (2006) assessed two further factors that could influence selection – (i) whether we need to have experienced the objects interacting with one another and (ii) whether the objects need to be positioned as if they are interacting together. Note that, in our original study (Riddoch *et al.*, 2003), we contrasted performance when objects interacted together with that when objects were assigned to unlikely co-locations. However, what happens when the objects are placed so that they are not interacting but do fall in locations where they could occur in the world (e.g. when the objects are side by side). Example displays are presented in Figure 2. We used objects that were either standardly used together in action (e.g. bottle and glass; see Figure 2), could be used in action but were not standardly used together (bottle and bucket), or that were (as far as possible) unrelated (bottle and ball – formed by randomly re-pairing the objects in the study). The objects were also shown interacting together or alongside one another. We found effects of both factors. Identification was best with objects that were standardly used together (bottle and glass > bottle and bucket), but it was also better with objects that could be used together than with randomly paired objects (bottle and bucket > bottle and ball). In addition, report was better when the objects were shown interacting than when they were shown side by side. Indeed, the advantage for the objects that could be used together over the random paired objects held *only* when the objects were shown interacting. These results show that the ability of the patients to attend to the pair of objects was influenced both by the familiarity of the objects being used together in action and by the visual layout depicting a possible interaction between the objects.



**Figure 2.** Example stimuli used by Riddoch *et al.* (2006) to examine the effects of visual affordance on extinction. Left – a familiar pair of objects positioned correctly for action. Right – an unfamiliar pair of objects positioned correctly for action (the visual affordance condition).

This set of findings, from patients with visual extinction, provide striking evidence for the selection of perceptual information being infiltrated by action. The reduction in extinction found even with objects that are not usually used together, provided they are shown in interaction, is consistent with the idea of affordance which was introduced to the literature by Gibson (1979). Gibson proposed that our perceptual systems respond to the 'fit' between the properties of the environment and the goal state for action present in a person. Note that this fit does not necessarily have to be based on some learned associative relationship between one stimulus and either other stimuli in the environment or the action that is part of the goal state. A fallen tree trunk may 'afford' sitting on when you are tired, even if you have never done this before. Our data indicate that selection is sensitive to the 'affordance' for action between stimuli.

Quite similar findings on patients showing visual extinction, and in a patient showing simultanagnosia (an impairment in seeing more than one object at a time), have been documented by di Pellegrino, Rafal, and Tipper (2005) and by Castiello, Scarpa, and Bennett (1995). di Pellegrino *et al.* presented patients with left extinction pictures of cups with their handles turned to the right or left. Extinction was reduced when the left side cup had its handle on the left, when it might evoke a left-hand grasp response. The effect did not appear to be due to the handle making the left side cup visually salient. In a control study, di Pellegrino and colleagues replaced the handle with another salient visual cue (a patch equated for position, size, and luminance to the handle) and failed to find any recovery from extinction. The data suggest that attention in the patients could be drawn to the action 'afforded' by the handle being on the left of the cup.

Castiello, Scarpa, and Bennett (1995) presented data from a simultanagnosic patient who was very impaired at reporting the presence of multiple objects. When shown two unrelated objects on cards and asked to bring them together, the patient showed very uncoordinated movements of the cards. In contrast, when the objects were functionally related, the patient was able to coordinate movements between the stimuli, indicating perceptual awareness of both items based on their common functional relationship.

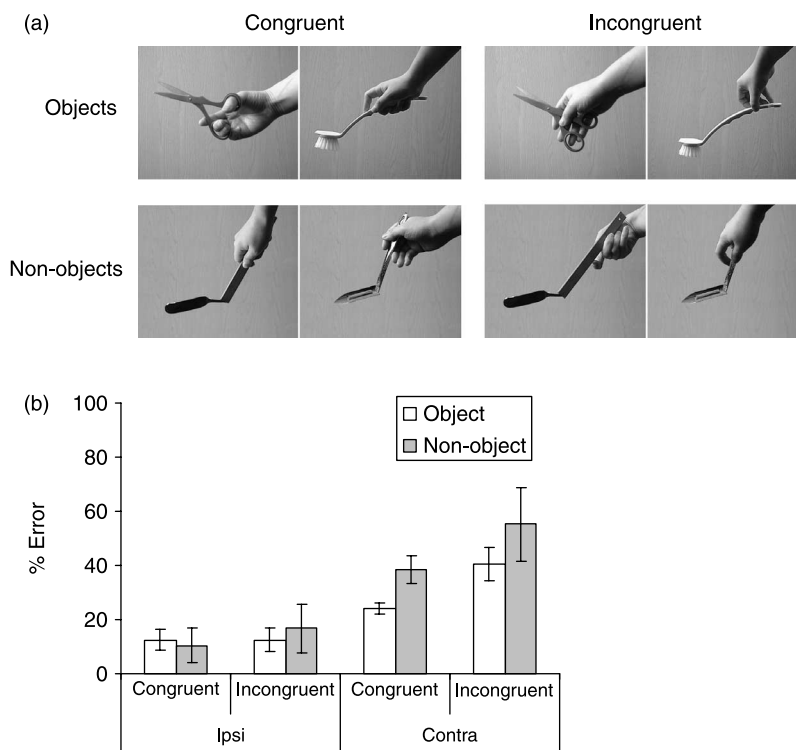
These effects of positioning objects for action on the ability of patients to select stimuli could reflect either some residual system not normally used, or they may be due to adaptation following lesioning of the visual attention system. In either case, the effects would not be informative about the processes that mediate attention in the normal population. Fortunately, for the argument that affordances influence normal selection, there is converging from work with non-lesioned participants. Green and Hummel (2006), for example, had participants verify whether the second of two objects matched a name given at the start of each trial. They found that verification was more accurate when the first stimulus was another object that was typically used with and was shown in interaction with the second object. This effect of positioning the objects for action occurred only when there was a short interval between the stimuli, under which circumstance perceptual integration between the objects was maximized. These data suggest that verification of the target was enhanced when the objects formed an integrated unit in interaction with one another, and the action depicted was consistent with the identity of the object.

#### *Are body parts grouped along with objects in action?*

How far can this effect of action-based coupling between stimuli be extended? For example, does our sensitivity to action lead to grouping taking place between objects



and parts of our own body, since we frequently see objects being grasped and manipulated by body parts as the objects are used? In some sense, are our own body parts integrated with the objects being used, to form a new perceptual representation? We have explored this question by again examining recovery from extinction in neuropsychological patients. We (Yoon, Chiavarino, Riddoch, & Humphreys, 2009) presented patients with stimuli such as those shown in Figure 3a in which a hand was shown grasping an object either correctly or incorrectly (using a grasp that should be applied to another object). We can think of these images as being equivalent to those with pairs of objects correctly or incorrectly positioned for action (cf. Riddoch *et al.*, 2003), except that one 'object' here is a body part. We asked whether the patients could better attend to both stimuli (the hand and the object) when the stimuli were correctly positioned for action (the object was gripped correctly) relative to when it was incorrectly positioned for action (the object was gripped incorrectly). The experiment also had one further complication. We presented the patients with hands grasping either familiar objects (scissors, handbrush; Figure 3a, top) or unfamiliar non-objects (the butterknife-ruler, the peeler-ladle; Figure 3a, bottom; the non-objects were made by combining the parts of two different objects). Thus we looked at whether the patients were able to report both stimuli (the hand and the object/non-object), whether this was influenced by how the stimuli were gripped, and whether it also depended on whether an individual stimulus was familiar or not (objects vs. non-object). The task was to report



**Figure 3.** (a) Examples of objects (top) and non-objects (bottom) gripped correctly or incorrectly for action. (b) The percentage of errors made on two item trials made by patients showing visual extinction to objects and non-objects gripped correctly and incorrectly for action (from Yoon *et al.*, 2009).

whether one or two stimuli were present (where two stimuli includes an object/non-object and a hand).

The data from four patients showing extinction are presented in Figure 3b. Detection of the presence of the tool-like stimulus was better on trials when the object was gripped appropriately for action than when it was not gripped appropriately. In addition, detection of objects was better than that of non-objects. These effects of whether the grasp was appropriate, and of whether the stimulus being grasped was familiar or not combined additively. This suggests that the two factors (appropriateness of grasp and object familiarity) exert independent influences on attention. Whether a grasp is appropriate or not influences whether the patients attend to *both* the hand and the object/non-object, or whether they attend to just one. When attention is drawn to just one of the stimuli, the patients show an extinction effect. This suggests that the patients can respond to an integrated perceptual unit involving both the hand and the object/non-object, when the stimuli are correctly positioned for action (when there is a correct grasp). It follows that the hand is part of the 'visual action unit' that is attended.

It is also important to note that the effect of showing a correct grip was equally large for objects and non-objects. Thus the 'visual action unit' is not limited to familiar objects but can include unfamiliar stimuli (non-objects) whose parts suggest a functional purpose. Again this fits with the Gibsonian notion of affordance as not necessarily reflecting a learned relation to an individual object.<sup>2</sup>

#### *Attention to action properties of single objects*

As well as visual selection being affected by the action relations between objects (and object and body parts), there is also evidence for effects on selection from action-related properties of single objects. In experiments using event-related potentials (ERPs) along with functional magnetic resonance imaging (fMRI), Handy and colleagues examined whether placing graspable objects in areas of field likely to be most strongly associated with a grasp response (particularly the lower right quadrant, for right-handed participants) influenced the orienting of visual attention. Their ERP experiment examined the visually evoked P1 component, which has previously been shown to increase in magnitude when stimuli appear at attended locations (e.g. Mangun & Hillyard, 1988). Handy, Grafton, Shroff, Ketay, and Gazzaniga (2003) found that the P1 component increased when tools were presented in the right and lower visual field compared with the left and upper visual field, whilst there were no effect of field on the P1 response to non-graspable objects. Tools presented in the right and lower visual field also selectively increased activation in brain regions associated with the formation of visuomotor associations and the planning of action, including the dorsal premotor cortex (PMd), the prefrontal region anterior to this (the pre-PMd), and the intraparietal lobule. From these data, Handy *et al.* propose that the change in the P1 reflected increased attention paid to tools when they fell in the right and lower visual field, and that this increased attention is associated with the activation of visuomotor associations to these stimuli. The suggestion is that tools generate a greater visual-orienting response

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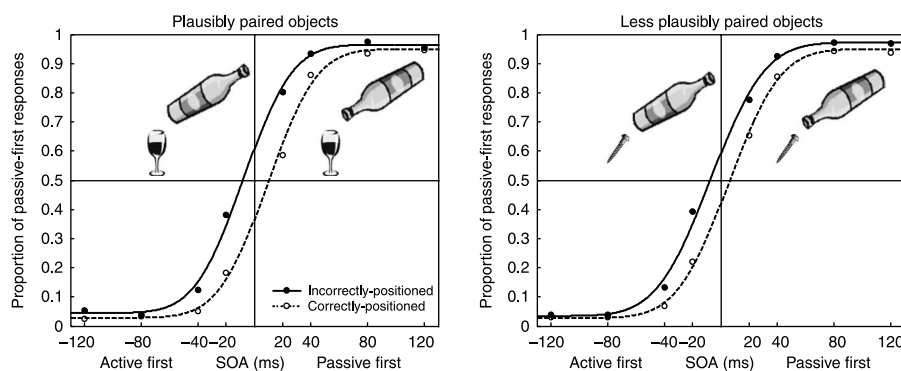
<sup>2</sup> It is interesting to speculate whether the incorporation of body parts into the 'action units' we respond to is linked to the tendency of some apraxic patients to use body parts as objects, when asked to gesture how to use the objects (e.g. a patient may move their hand through their hair to indicate how to use a comb rather than gripping a virtual comb above their head). It may be that degradation of the action units may lead to the body part and object running together, so they are no longer distinct.



when they fall in a location where these stimuli are most strongly linked with a visual grasp response. We return in the section on 'The effects of goal states for action on attention' (below) to examine evidence that attentional responses to objects can be enhanced not only when the objects afford an action, but also when that action matches the intention of the observer.

Other evidence for enhanced selection to the action-related properties of individual objects comes from studies of temporal order judgments (TOJs) in normal participants. Our ability to judge the temporal order of object onsets is affected by attention; we tend to judge as appearing earlier objects to which we attend (Shore, Spence, & Klein, 2001). In neuropsychological patients, chronic spatial biases in visual processing can lead to TOJs in which items on the 'good' side are consistently deemed to appear before items on the 'bad' side (Rorden, Mattingley, Karnath, & Driver, 1997). In addition, TOJs are sensitive to grouping. When two objects group TOJs become more difficult, leading to a flattening of the function for discriminating which object came first and which second (Nicol & Shore, 2007). Roberts and Humphreys (2009) had normal participants make TOJs to pairs of objects that were either correctly or incorrectly positioned for action (Figure 4). They found that correctly positioning objects for action did not affect the shape of the discrimination function (as would be expected if grouping between action-related objects influenced the TOJs), but it did lead to a constant shift in which the 'active' object (cf. Riddoch *et al.*, 2003) tended to be judged as appearing first. This result held even with pairs of objects that are unlikely to interact with one another. The lack of a grouping effect here may be due to the TOJ task emphasizing attention to individual objects. Irrespective of this, the shift to judge that active items appear first, when the objects are positioned for action, indicates that there is prioritized processing to these objects. Here positioning of the active object for action enhanced its processing even when it did not group with its partner.

The data reported by Roberts and Humphreys (2009) suggest that there may be two factors that influence attention when objects are positioned for action. One is perceptual grouping between the stimuli (e.g. as shown when patients show less



**Figure 4.** Data from Roberts and Humphreys (2009). The results represent TOJ decisions (the proportion of trials where the 'passive' object in a pair was judged to have come first). The curves for correctly positioned objects take the same form as those for objects incorrectly positioned for action, but the former are shifted to the right. This indicates a bias to judge the 'active' member of each pair as appearing earlier when the objects are correctly rather than incorrectly positioned for action. The results do not differ for familiar pairs of objects that plausibly interact with one another and for unfamiliar pairs that less plausibly interact together.

extinction) and the other is enhanced processing based on positioning individual objects for action (as also in Handy *et al.*, 2003). Note that these data, on attentional enhancement based on the action properties of individual objects, go beyond other results which indicate that individual objects can evoke an internal action-based response even when that is irrelevant to the task (e.g. Tucker & Ellis, 1998). The experiments of Handy *et al.* (2003) and Roberts and Humphreys (2009) showed enhanced perceptual processing in relation to the evoked action.

### **Action relations and selection of members of a perceptual group**

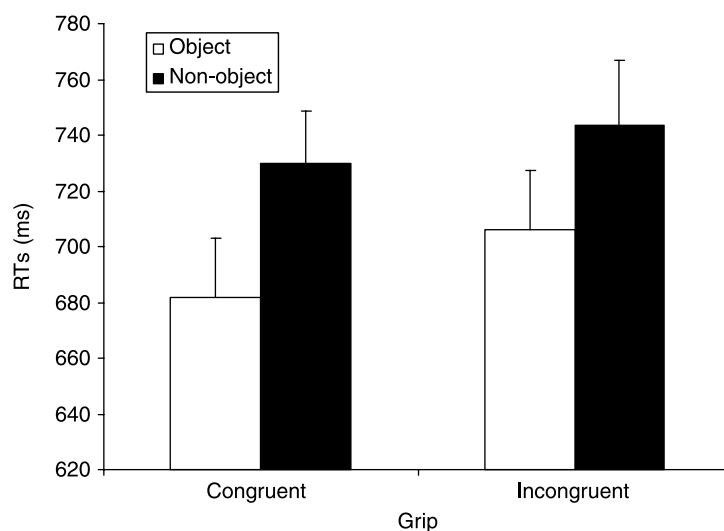
There are consequences of visual grouping on the ability to select individual members of the group. When stimuli group on the basis of Gestalt factors such as connectedness and similarity, attention tends to be drawn to the whole group making it difficult to select an individual component member (e.g. Baylis & Driver, 1992; Rensink & Enns, 1995). In cases where the members of the group are associated with different responses, response selection is difficult (Baylis & Driver, 1992). Similar results can be found when stimuli group by action.

Yoon and Humphreys (2005) assessed how interactions between an object and a hand affected response selection to the object. They presented observers with objects that were grasped correctly for action or that were grasped inappropriately (see Figure 3). Simultaneous with the picture, stimulus participants were given a word describing the action that either was or was not usually carried out with the object (e.g. cutting vs. combing, Figure 3). The task was to verify whether the word described the action that would be performed with the object, with the hand being irrelevant to the task. Despite the hand being irrelevant, action-verification responses were affected by whether the objects were grasped appropriately for action by the hands. Responses were faster when the grasp was appropriate for the action compared with when it was not; also, relative to when the object appeared alone, responses were slowed when the grasp was inappropriate. This cost, on trials where the grasp is inappropriate, indicates that the result is not simply due to the grasp providing an extra cue to the identity of the object – the inappropriate grasp disrupts the response to the information that is available in the object.

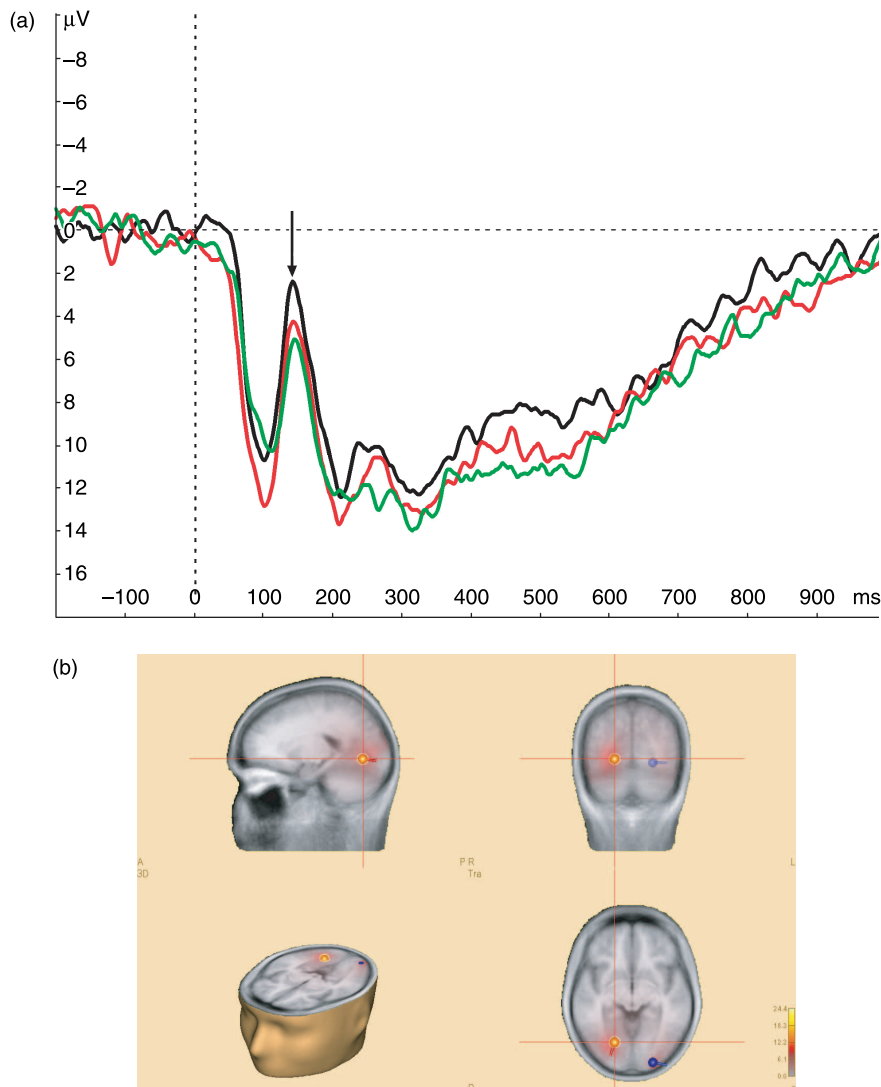
The result reported by Yoon and Humphreys (2005) is consistent with participants finding it difficult to attend to the object due to it grouping with the hand, and then being affected by whether the perceptual unit formed by the object and the hand ‘afforded’ the action proposed in the verification task. This is similar to data from the well-known ‘Eriksen flanker’ task, where responses to a target are affected by an irrelevant distractor (e.g. responses are slowed if a flanking distractor requires a different response to the target). In the Eriksen flanker task, interference increases if the visual elements group (Baylis & Driver, 1992, 1995). However, the result reported by Yoon and Humphreys (2005) does not *demonstrate* grouping, and interference could arise even if the items are not grouped but are coded independently and activate separate responses – in the example in Figure 3 the incorrect grip applied to the scissors may signal ‘lifting’ and the independently activated responses of ‘cutting’ and ‘lifting’ may make the response to ‘cutting’ more difficult. In other work we have had participants decide whether the depicted object was real or not (i.e. participants performed object decision responses). We used grasps were either congruent or incongruent with the use of the stimulus but the grasps were, in all cases, actions that could be applied to objects. In this case, both action-congruent and action-incongruent

grasps were consistent with the response to a real object. This should eradicate effects of interference in the action-incongruent condition due to two different responses being evoked, since the same response (object) should be generated by the object and correct and incorrect grasps alike. Despite this, object responses were faster when the objects were grasped appropriately for action compared with when they were not (see Figure 5). In this case, the disruption from the incongruent grasp cannot be due to response competition from a hand grasp that is coded independently of the object; instead the data suggest that participants respond to the hand grasping the object as a single unit. Performance is then affected by whether this overall unit is consistent or inconsistent with the response to the object (when the grasp is respectively congruent or incongruent with the action typically performed with the object).

We have examined the time course and neural basis of these effects using ERPs and fMRI. In both cases participants made decisions as to whether objects were real or not under conditions in which the objects were grasped appropriately or inappropriately for action. The ERP data (Kumar, Yoon, & Humphreys, 2009) revealed a divergence in the neural response to objects that were grasped appropriately for action, relative to when the grasp was inappropriate, emerging around 130–150 ms after the onset of the stimulus. The N1 component, reflecting the ease of perceptual encoding, was increased when the objects were grasped appropriately compared with when the grasp was inappropriate for action. This divergence emerged at a number of electrode sites over parietal, temporal, motor, and frontal cortex; however, dipole modelling suggested a single source for the effect located bilaterally in occipital cortex (Figure 6). In addition, there was a difference between grasp-appropriate and grasp-inappropriate stimuli in the so-called 'lateral readiness potential (LRP)', a difference in activation across the hemispheres reflecting the preparation of a response with the contralateral hand. LRPs occurred earlier for grasp-appropriate than for grasp-inappropriate displays. These data are consistent with an early visual response based on whether objects are grasped appropriately or inappropriately for action, which is translated through to the earlier



**Figure 5.** Data from object decision responses made by normal participants to objects and non-objects gripped correctly or incorrectly for action.



**Figure 6.** (a) The mean averaged waveform showing the NI ERP response (timing indicated by the arrow) to objects and non-objects in an object decision task in which the stimuli were depicted as being gripped correctly or not (see Figure 3a). Red, incongruent grip; green, neutral (object only); black, congruent grip. (b) The results of dipole modelling applied to the electroencephalographic data from an object decision task with objects and non-objects gripped correctly or incorrectly for action. Here are the effects for objects gripped correctly (Kumar et al., 2009).

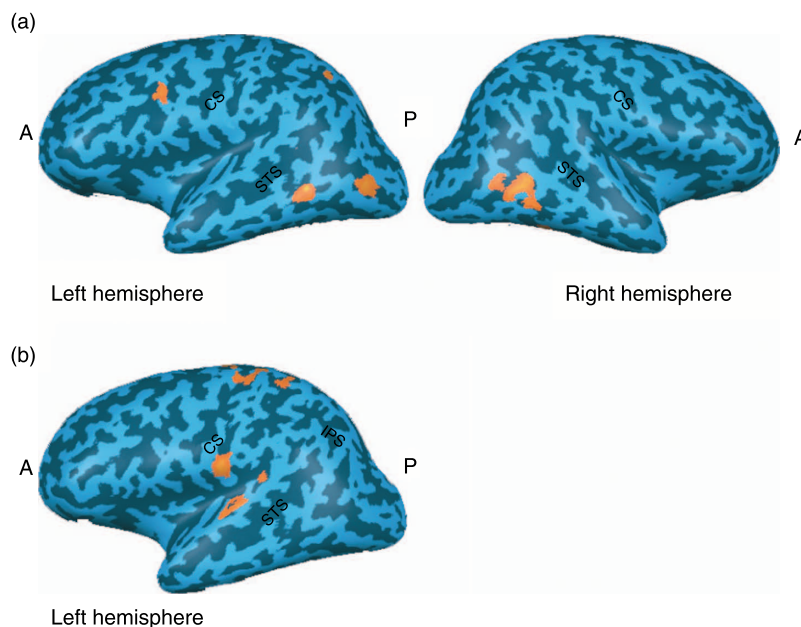
selection of a motor response (reflected in the LRPs) when the grasp is appropriate for action.

In an fMRI version of this experiment, we (Lestou, Yoon, & Humphreys, 2009) found activation in two main contrasts. First, there was a main effect of whether the stimuli were grasped appropriately or inappropriately for action with there being increased bilateral activation in the lateral occipital complex (LOC) when stimuli were gripped

inappropriately (Figure 7a). This held across both objects and non-objects. The LOC has been linked with visual object recognition (Grill-Spector *et al.*, 1999). We suggest that these data represent increased processing when there is a poorer match with stored representations reflecting the affordance of the stimulus for action. Second, there was increased activity selective to when known objects were gripped correctly for action, with activation raised in several more anterior regions in the left hemisphere associated with motor programming and sensory-motor interactions (including area PMd (cf. Handy *et al.*, 2003), the pre- and central sulci and the post-central gyrus; Figure 6b). These anterior activations are consistent with a strong motor response being evoked by the affordance generated particularly by the familiar object when it is gripped correctly. The ERP results indicate that these motor-based activations may be 'driven' by the visual response evoked by objects grasped for action.

#### The effects of goal states for action on attention

One of the interesting aspects of J. J. Gibson's original arguments about affordances is that he proposed that the degree to which a scene affords an action will depend upon the goal state of the participant. The same scene may not generate the same action-associated response if the participant has a different goal state – the fallen trunk may



**Figure 7.** (a) Group activation maps for incorrectly gripped stimuli over correctly gripped stimuli in an object decision task (averaged over objects and non-objects). Activations are overlaid on a participant's inflated surface rendering. (b) Group activation map for the interaction of correct grip for objects and incorrect grip for non-objects (interaction term: ObjectsCorrect + Non-objectIncorrect > ObjectsIncorrect + NonObjectsCorrect). Only the left hemisphere is shown. There were minimal activations in the right hemisphere (from Lestou *et al.*, 2009). A, anterior; P, posterior; CS, central sulcus; STS, superior temporal sulcus; IPS, intraparietal sulcus (from Lestou *et al.*, 2009).

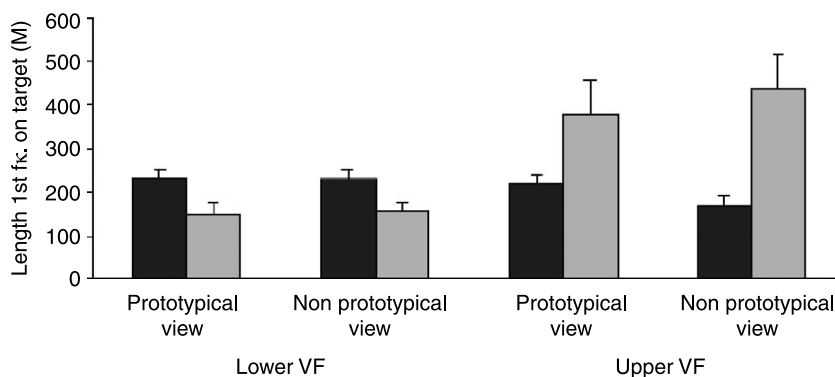
afford sitting if you are tired but throwing if it is blocking your way! There is evidence that the goal state for action can moderate how visual selection operates. Our own work on this topic began (again) with a neuropsychological study. We followed-up on a chance remark made by a patient we were working with who showed unilateral visual neglect (a general failure to respond to stimuli on the contralesional side of space, not only under conditions of bilateral simultaneous stimulation – like extinction). This patient, MP, reported that he was often unable to find things around his house but he felt that, if he thought about what he was supposed to do with them, he was sometimes able to detect them on his ‘bad’ side. We (Humphreys & Riddoch, 2001) assessed this more formally by having MP search across arrays of everyday objects, cueing him to find an object defined by its name (find the cup) versus cueing him to find an object defined by its action (find the object you would drink from). We found a striking difference between MP’s ability to find objects when cued by their names or their actions, with neglect being reduced when he was cued by action. To interpret these results, we suggested that MP was impaired at matching visual information from his contralesional side with a ‘template’ based on any perceptual or semantic properties evoked by the name. On the other hand, he was able to match contralesional stimuli against a template specifying the functional use of objects. According to this account, this ‘functional’ template would be separate to any perceptual information used to match an object to its name, it would respond to the potential of the object for action, and it continued to operate even though MP had sustained unilateral right hemisphere damage to posterior parietal and superior temporal cortex. It was also of interest that the effect held only when objects were oriented so that their handles were turned towards MP, when we presume the affordance for action is strongest (see also Creem & Proffitt, 2001; Yoon & Humphreys, 2007). The orientation of the objects had no effect on whether MP could identify individual stimuli; the effect was only when he cued to search ‘by action’. The data suggest that MP’s ability to orient to objects on his contralesional side, on the basis of any affordance for action, was maximized by giving him the goal set of searching using a functional description of a target object.

Following this initial study, other investigators have shown effects of the goal-set for action on attention in normal participants. For instance, Bekkering and Neggers (2002) had normal participants search for a target defined by a conjunction of its colour and orientation (e.g. find the red horizontal bar). In one case, the task was to point to the target, in the other it was to pick up and grasp the target. Bekkering and Neggers found that the first saccade made by participants was affected by the action required in the task. When a grasping response was demanded, the first saccade tended to go to distractors having the same orientation as the target; however this was less likely to be the case (e.g. first saccades tending to go to distractors with the same colour as the target) when a pointing response was required. This suggests that object orientation was assigned a stronger ‘weight’ in the selection process when a grasp rather than a pointing response was made. Fagioli, Ferlazzo, and Hommel (2007) further argue that contrasting actions can lead to variations in how different dimensions of visual stimuli are ‘weighted’ during the selection process. They had participants watch video clips of a grasping or pointing action prior to being given a task of detecting a target that deviated from a sequence of other stimuli in terms of either its size or its location. Watching a grasp action prior to the search task facilitated responses to a size-defined target, while watching a pointing action facilitated responses to a location-defined target. These results suggest that activating a grasp action leads to strong ‘weighting’ of the size dimension while watching a pointing actions ‘weights’ location codes when search is for



a disparate target. The goal-set for different actions has consequences for the types of visual information that are attended.

Forti and Humphreys (2008) followed-up on the work with patient MP by cueing normal participants to find a target defined in terms of its name or its function. The objects were also correctly oriented for action or shown in another orientation. These authors found that the effect of object orientation was stronger when participants 'searched by action' than when participants searched on the basis of the object's name. In addition, the length of the first fixation on objects, prior to the object being identified, varied both as a function of the task (search by action vs. search by name) and whether the object fell in the upper or lower visual field. Fixations were longer when participants 'searched by action' than when they searched on the basis of the object's name. This result is not surprising, given that many more objects could potentially fit with a functional description of an object than would fit the object's name (think of how many objects could be drunk out of vs. how many objects could be named a cup); the 'search space' is wider for any functional than any name description of an object. More interestingly, fixations were longer for objects in the upper than the lower visual field, but only when objects were defined by their function. In this case, fixations were particularly prolonged when the stimuli were also not depicted in a prototypical orientation for action (see Figure 8). The advantage for objects depicted in the lower visual field is reminiscent of the data reported by Handy *et al.* (2003), where an enhanced P1 was found for tools falling in this region. There are stronger projections from the lower visual field into posterior parietal cortex (PPC, e.g. area V6A; Galletti, Fattori, Gamberini, & Kutz, 1999), so the lower field advantage may be taken as a marker for the involvement of PPC in processing. Given the involvement of PPC in the control of action (e.g. Battaglia-Mayer *et al.*, 2001; Marconi *et al.*, 2001), we may speculate that the PPC is recruited when participants use a functional description of an object to direct attention in a top-down manner, and this gives rise to the lower field advantage. It can also be argued that most actions are performed to objects presented in that part of space (Previc, 1990), so that having a functionally defined target biases attention to that spatial region. This last argument is consistent with the proposal that goal states for action modulate how attention is paid to visual displays.



**Figure 8.** The mean durations of fixations made to targets defined by their name or by the action that would be performed with them, shown here as a function of whether the target fell in the upper or lower visual field, and according to whether the target was in a prototypical or non-prototypical view for action (from Forti & Humphreys, 2008). Black bars = search cued by the object's name. Grey bars = search cued by action.

Differences between the effects of grasping and pointing actions on the allocation of visual attention have also been revealed through neuropsychological studies. There are now several reports contrasting grasping and pointing on the expression of visual neglect. A typical finding with neglect patients is that they make errors when asked to mark the centre of a line, tending to mark the centre too far to the ipsilesional side ('neglecting' the contralesional side; see Halligan & Marshall, 1988). Errors of this type also occur when the patients have to mark the centre of a rod by pointing. However, when the task is to grasp the rod and pick it up, then patients can show reduced neglect, so their grasp action is more likely to go to the centre of the rod (Edwards & Humphreys, 1999; Robertson, Nico, & Hood, 1995, 1997). Again having a different action goal state seems to influence visual attention and, in this case, the grasp action leads to the patient paying more attention to the neglected side.

Recently, Symes, Tucker, Ellis, Vainio, and Ottoboni (2008) have shown that preparing a particular action can also sensitize participants to detect particular changes in visual displays. They used a change blindness procedure in which participants prepared to make either a power or a precision grip response when they detected a change to an object in a flickering display. The detection of changes to objects that were consistent with the prepared grip was enhanced, relative to when changes were made to objects that would be acted upon with a different grasp. Interestingly, this same result occurred when participants had to withhold a planned grasp response and instead respond with their foot. This last result suggests that the effect on detection was not due to an object consistent with the grasp activating the grasp response more readily, but rather the data reflect the biasing effects of motor preparation on attention to visual attributes consistent with the planned motor response.

In Symes *et al.* (2008), the effect of motor preparation was on detecting a changing target stimulus. Kitadono and Humphreys (2009) went beyond this by examining whether preparation of a motor response influenced detection based on aspects of a stimulus that were irrelevant to the task. They used stimuli similar to those in Figure 3, with each object shown either being correctly grasped or being pointed to by a hand. On each trial, participants were cued to detect a particular target (e.g. scissors), which was shown being grasped or pointed at, falling on the left or right side of space. On the opposite side of space, an irrelevant distractor was presented with the opposite hand response to that depicted for the target (i.e. if the target was grasped, the distractor was shown with a hand pointing to it). Participants had to make a speeded grasp or point response on a manipulandum, before indicating whether the target fell to the left or right of space. Reaction times were faster when the irrelevant hand shown along with the target was congruent with the action prepared by the participant. Here motor preparation potentiated the response to a matching, irrelevant motor action. This may in turn reflect the treatment of the hand and the target object as an integral perceptual unit (cf. Yoon & Humphreys, 2005).

Effects of planning a particular motor response on visual attention have also been noted by Linnell, Humphreys, McIntyre, Laitinen, and Wing (2005). They used a paradigm introduced by Deubel, Schneider, and colleagues (e.g. Deubel, Schneider, & Paprotta, 1998; Schneider & Deubel, 2002) in which participants prepare to make a motor response to a given location and the effects of preparing this motor response on visual perception are examined. Deubel *et al.* (1998) demonstrated that attention is closely coupled to the motor response, so that there is facilitated detection of visual targets falling at the end location of the planned action. Visual target detection is affected by the planned pointing action even when the target always appears at the

same location and the action is planned to another position. Kitadono and Humphreys (2007) report similar effects in patients with visual neglect, where planning an action to a region on either the ipsi- or contra-lesional side of space can respectively increase or decrease neglect, even when patients remain fixated and when the visual stimuli are exposed long before any action is effected. Planning the action can enable a neglected part of space to be attended. Linnell *et al.* (2005) extended this work by showing that a planned pointing action can even override the grouping of visual elements into objects. These investigators used displays in which visual targets appeared in circles, and neighbouring circles could be joined to form 'barbells'. In their Expt 1, participants were given a visual cue to attend to one circle. The detection of a target in an adjoining circle was then facilitated when the cued and the target circle were connected into a barbell, relative to when the circles were parts of different barbells (see also Egly, Driver, & Rafal, 1994). This result is consistent with visual attention being allocated across the barbell object created by connecting the elements. In Expt 2, participants had to plan a pointing action to one circle within a barbell. In this case, there was no longer any facilitation for targets falling in the other circle in the same object, relative to when the targets appeared in a neighbouring circle that was part of a different object. Thus the effects of grouping on attention were eradicated. These results are consistent with the planned motor action modulating the way that visual information is coded – for example, enhancing the local region where the action is programmed to but disrupting grouping between other elements. Again the findings suggest that action can have a pervasive effect on how attention is allocated to visual displays.

### ***The driving mechanisms***

We have presented data indicating that attention is not only affected by action in a general way (e.g. based on our having only a limited number of effectors), but also that there are deep effects of action on how attention operates. Attention is allocated to multiple interacting objects as a single 'unit', it is difficult to attend selectively to one object when it is part of such an interacting 'unit', and the goal set for action moderates how visual information is 'weighted' for selection. The question arises, then, as to how these effects of action on attention may come about. We discuss two possibilities: *statistical learning* and *motor feedback*.

### **Statistical learning**

One possibility is that action information comes to modulate visual attention due to actions providing important statistical information about the nature of the visual world, and this statistical information governs how attention is allocated. We have already noted evidence that attention is affected by the familiarity of objects, for example, enabling familiar objects (e.g. words) to be attended as a single perceptual unit (Kumada & Humphreys, 2001). Now, consider an everyday scene in which there are multiple objects present. In such scenes, the visual information present is typically in a constant state of flux, as objects move or are moved around, or as we view the scene from different angles. Given the changes taking place, it may be difficult to learn the representation of the scene as a single object, and learning may be restricted to those elements in the scene that remain fixed across different encounters. This limitation is less severe, however, for learning the relations between pairs of objects, since these

relations may be more consistent across time and space. In particular, stimuli that are part of a common movement in a scene, such as two objects that are picked up and used together, will tend both to be spatially close together and to be linked within the same temporal event. This common appearance, within an action event, will increase the co-occurrence statistics for the stimuli, and along with this, the chances that the objects are coded as part of a single perceptual object. Take another example of sitting at a kitchen table where there are multiple objects present (a milk jug, a vase, a cup, a pair of scissors, salt, a knife). These objects may occupy arbitrary positions according to when they were last used and put down. This should make it difficult for our visual systems to learn the relations between the objects (e.g. between the jug and the vase). However, the objects that are frequently used together (e.g. the jug and the cup) will have raised co-occurrence statistics – for example, they will tend to be seen in close proximity and they can both be in motion at the same time. We contend that objects that are part of such action events benefit from these raised co-occurrence statistics and come to be coded as a single ‘action unit’. When separate objects are depicted in interaction, then, they can activate this stored unit, which in turn drives attention across the individual objects making up the unit (see Heinke & Humphreys, 2003, for an explicit simulation of how attention can be allocated to component elements making up a single stored representation). Though a statistical learning process will be sensitive to non-action as well as action-based regularities in the world, regularities determined by action will exert a powerful influence given that actions determine visual events.

The argument here is that actions determine co-occurrence statistics in the world, and so they lead to the visual environment being parsed in ways that are sensitive to the action relations between objects. The learning that takes place may be sensitive to particular objects being used together, but learning may also operate on the basis of common features across different instances of objects so that ‘action units’ become (to some extent) abstracted from particular instances. It may be through this abstraction process that attention can be allocated to novel pairs of objects that interact in a plausible way, even if you have not seen the objects used this way before. For example, attention may be allocated to the interacting wine bottle pouring into a bucket (Figure 2) because the bottle has features similar to those of other pouring vessels and the bucket has features of other containers. Statistical learning through both particular objects and common features may provide a visual mechanism for affordances to influence attention. Note that this argument is supported by evidence from both ERPs and fMRI that visual brain regions respond differentially according to whether objects are grasped in a manner that is plausible for action (Kumar *et al.*, 2009; Lestou *et al.*, 2009).

### **Motor feedback**

A second possible mechanism that could generate effects of action on attention is feedback from the motor system, which may act in a re-entrant manner to influence earlier visual processes. This notion, of motor feedback ‘driving’ attention, has similarities with the ‘pre-motor’ theory of attention proposed by Rizzolatti and colleagues (Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Rizzolatti, Riggio, & Sheliga, 1994), and similar ideas also form part of the ‘integrated competition’ hypothesis (Duncan *et al.*, 1997) and VAM (Schneider, 1995). One difference with pre-motor theory is that pre-motor theory holds that attention to a location is nothing more than the plan to make an action (e.g. a saccade) to that location. On the other hand, we suggest

that motor associations to objects may be generated, which then feedback to affect perceptual processing (e.g. influencing perceptual decisions such as TOJs; Roberts & Humphreys, 2009). These feedback signals act to provide a competitive advantage for stimuli appearing at locations to which the movements are programmed. This was originally proposed in the context of the effects of eye movements on visual attention, but work such as that of Deubel *et al.* (1998), Kitadono and Humphreys (2007), and Linnell *et al.* (2005) indicates that feedback from programmed upper limb actions is also effective in 'pushing' visual attention to locations held by the motor system as targets for action. In our view, the attention system is permeated by prepared actions along with action-based responses evoked by individual and pairs of objects. The influences of action on attention occur within the visual system, evidenced by effects on early ERP components and on TOJs. Pre-motor theory, on the other hand, holds that prepared actions account for the distribution of attention *over* but not *within* visual representations.

The data we have discussed on the effects on attention of preparing a motor action clearly fit with the proposal that motor feedback influences visual attention (Kitadono & Humphreys, 2009; Symes *et al.*, 2008). This proposal can also explain effects of the positioning of the handle on extinction effects with cups (cf. di Pellegrino, Rafal, & Tipper, 2005), if having a handle to the left side activates action programming to this stimulus. One interesting aspect of the idea that visual attention can be directly mediated by motor feedback is that this feedback process may operate differently for different individuals. For example, if the feedback effects link directly to a participant's body, then they will vary with factors such as body size (motor feedback effects may cover a wider area in larger individuals); the effects may vary with the reference frame that objects appear in (e.g. coded from the participant's own view or not) and so forth. These remain interesting issues to be explored.

The motor feedback account alone, however, seems inadequate to account for all the ways in which the 'visual potential for action' influences attention. For example, in pairs of interacting objects, the 'active' object (manipulated in the action) may be positioned on the ipsilesional side of patients, but there can still be recovery of extinction in such cases (Riddoch *et al.*, 2003). If participants oriented attention to the ipsilesional side, we might expect extinction to worsen not improve. A visual response to the potential for action between the objects then seems to be critical. This may operate in addition to any effects of motor-based responding to the action related properties of individual objects. Motor-based responding is indicated by our data on TOJs, where there was no apparent effect of grouping but an effect of positioning the 'active' object for action (Roberts & Humphreys, 2009).

To account for the results, we propose that a theory is required in which visual properties of objects activate recognition units for individual objects but also for action-related pairs of objects, and these in turn evoke a response that may lead to motor feedback on attention. The properties critical for these effects may include information about implied motion between the objects, while our data (Riddoch *et al.*, 2006) indicate that the mediating representations are sensitive to stored knowledge about particular objects as well as to relations between more local parts which can occur across many objects. Whatever the case, the ERP and fMRI data we have presented, indicating where and when in the brain visual information consistent with action becomes activated, fits with the notion of visually-driven affordances to action as well as motor-based responding taking place. Statistical learning, sensitive to spatio-temporal contingencies in the environment determined by action, provides a mechanism by which such visuo-motor affordances may be evoked.



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