Implied actions between paired objects lead to affordance selection by inhibition

Xu, Shan; Humphreys, Glyn; Heinke, Dietmar

DOI:
10.1037/xhp0000059

Implied actions between paired objects lead to affordance selection by inhibition

Shan Xu

University of Birmingham

Glyn W. Humphreys

Oxford University

Dietmar Heinke

University of Birmingham

Author note

Shan Xu, School of Psychology, University of Birmingham, Birmingham, UK; Glyn W. Humphreys, Department of Experimental Psychology, Oxford University, Oxford, UK; Dietmar Heinke, School of Psychology, University of Birmingham, Birmingham, UK

Part of the results has been presented as a poster in the Thirteenth Annual meeting of Vision Sciences Society (VSS 2014).

Correspondence concerning this article should be addressed to Shan Xu, School of Psychology, University of Birmingham, Birmingham, B15 2TT, UK. Email: sxx127@bham.ac.uk

Abstract

Evidence from experiments with single objects indicates that perceiving objects leads to automatic extraction of affordances. Here we examined the influence of implied between-object actions on affordance processing. Images of task-irrelevant object pairs (e.g. a spoon and a bowl) were followed by imperative central targets. Participants made speeded left/right responses to targets, and the responses randomly aligned with the affordance of one of the objects. The orientation of one object was manipulated across trials, leaving the co-location between objects correct or incorrect for potential interaction. Four experiments demonstrated that positioning the objects correctly for between-object actions led to a prioritization of the object active in the action (e.g., the spoon) over the passive (e.g., the bowl) object. Moreover, there was an inhibitory effect on responses to the passive object: responses congruent with the passive object were slower when pairs of objects were shown as if in interaction, compared with when they were not. The effects did not change in single-hand response task but disappeared when the passive objects were absent - though an affordance should still have been presented by the active object. These results present evidence for affordance selection in action-related object pairs, and suggest inhibition of the action afforded by the passive objects under conditions of affordance competition.

Keywords: paired objects, implied actions, action relation, affordance selection, inhibition

In his seminal book, Gibson (1979) postulated that humans directly detect action possibilities (affordances) from the physical properties of objects in the environment in an automatic fashion. There is now substantial evidence for this claim (e.g. Bub, Masson, & Cree, 2008; Phillips & Ward, 2002; Riddoch, Edwards, Humphreys, West, & Heafield, 1998; Riddoch, Humphreys, Edwards, Baker, & Willson, 2003; Tucker & Ellis, 1998). This paper aims to examine how the selection of affordances plays out when we see two objects. In particular, how is affordance processing influenced when these objects are commonly used together, e.g. a spoon to scoop from a bowl? One possibility is that the perceived affordances are not affected by the pairing, i.e. the spoon is seen "pick-up-able" and the bowl still considered being "lift-able". On the other hand, the affordance of the bowl may be suppressed, e.g. in order to successfully execute the reach for the spoon. In other words, the affordance of the object relevant for an immediate action might be selected while the other object's affordance might be suppressed. This paper explores whether a competitive process of affordance selection exists or whether the detection of the affordance is unaffected by the potential interaction between two objects.

Primary evidence for the detection of affordances from single objects (e.g. Bub, Masson, & Cree, 2008; Phillips & Ward, 2002; Tucker & Ellis, 1998) is based on an experimental procedure sometimes termed the response compatibility paradigm. In these experiments participants are asked to indicate a property of an object which is largely unrelated to the object affordance. Despite being irrelevant to the task the object affordance affects the participants' response. For instance, in their Experiment 1 and 2, Tucker and Ellis (1998) presented photographs of common graspable objects as stimuli, and the participants had to indicate the vertical orientation of the objects (upright or inverted) by making left-right key press responses. They found that when the graspable parts of the objects (e.g., the handle of a frying pan) were aligned with the responding hand reaction times were faster compared to when the handle pointed to the opposite of the responding hand. Subsequently, this finding was extended by Phillips and Ward (2002). They showed that the affordance of the object affected the left-right key responses to a stimulus (abstract symbol) placed on the object. Hence the affordances of objects were detected even though objects are irrelevant to the task. Overall, these findings suggest that there is automatic extraction of affordance.

The detection of affordances in a two-object scenario was examined in a series of studies by Humphreys and colleagues (e.g. Riddoch et al., 2003). In these studies participants see object pairings where one object is “active” while the other object is “passive”. Active objects (e.g. a spoon in a spoon-bowl pair) are those items used in the action between the objects (e.g., grasping and scooping from the bowl), while the passive objects only need “stabilization” (e.g., the bowl in the spoon-bowl pair). Importantly these studies show that responses are affected if the objects appear to interact with each other in a typical way. For instance, Riddoch et al. (2003) reported data on patients with visual extinction[1] who show impaired detection to stimuli on the contralesional side of a display when another item is present on the ipsilesonal side. The impairment in detecting contralesional items was alleviated if paired objects were presented one on each side and as if interacting with each other. Here positioning objects for action enabled the patients to attend to both members of a pair. In contrast, there was still extinction if the objects were positioned not to interact with each other. Similarly, in normal participants, correctly co-locating stimuli for action improves the identification of briefly presented objects, compared with when the objects are positioned not to interact (e.g. Roberts & Humphreys, 2011a). These studies also find a bias towards the active objects. That is, with both patients (e.g. Riddoch et al., 2003) and neurologically typical participants (e.g. Roberts & Humphreys, 2010a), response benefits tend to go with the active member of an interacting pair. For instance, when the patients with extinction reported only one object in a pair positioned for interaction, it was more likely to be the active object, regardless of whether the active object fell on the contralateral or ipsilateral side. These results can be interpreted as evidence for the affordance from the interacting objects being coded pre-attentively, since patients are unaware of the contralesional stimulus unless it is paired correctly for action. This affordance further determines which of the two objects is preferentially selected (with a bias towards the active member of the pair).

In addition, there is also evidence suggesting competition among different objects. A study by Ellis, Tucker, Symes, and Vainio (2007) examined the extraction of affordances in a two-object scenario using the response compatibility paradigm. Unlike Riddoch et al. (2003; also Roberts & Humphreys, 2010b), the objects were unrelated to each other and they were not positioned to interact.

[1] Patients with visual extinction can detect a single item presented on the side contralateral to their lesion but fail to detect the same item when it is placed in competition with another item on the ipsilesional side. The deficit can be conceptualised in terms of the lesion introducing a spatial bias in the competition for selection between the stimuli (Duncan, Humphreys, & Ward, 1997).

Participants were asked to indicate a simple geometric property (straight or curved) of a target object by making a power grasp or a precision grip, and the other item was a distractor. When the target object was defined by its colour, Ellis et al. found that required grasps were delayed if the distractor requires a compatible grasp, relative to when the distractor affords an incompatible grasp. The data suggest that there can be competition for action selection between a target and distractor objects, which must be resolved in order to select the action to the target (see also Pavese & Buxbaum, 2002). The time for resolution is increased when the distractor's response is compatible with that required for the target. Other authors have also argued that there can be competition for action selection between affordances offered by single objects (Boehme & Heinke, 2009; Cisek & Kalaska, 2010; Riddoch, Humphreys, & Price, 1989; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013).

Although previous studies have argued for the role of affordance competition in visual processing, there has been little direct evidence for such competition for paired objects. The present study provides novel evidence on this. We evaluated whether there was competition for action selection between the affordances offered by individual objects that are presented simultaneously, and in particular whether this competition leads to inhibitory processing in order to perform between-object actions. Consider our example of a spoon and a bowl. For the two objects to interact as a pair it requires that the spoon is actively used and the bowl stabilised. However, the bowl itself could afford a lifting action which would be incompatible with the action to the objects as a pair. This may create competition for action selection which may need to be resolved – for example by inhibiting the response to the bowl.

To assess this, we combined the paired-object design (Riddoch et al., 2003) with the procedure reported by Phillips and Ward (2002). Participants were asked to respond to an imperative stimulus in the centre of the screen (square or triangle) with a left/right response while a task-irrelevant object pair was simultaneously presented (see Figure 1). The left object in the pair would afford a left response and the object on the right a right response. Hence, analogous to Phillips and Ward's (2002) findings, responses to the imperative target should be affected by the affordance of the object aligned with the response. In our procedure, for instance, an active object may lead to a speed-up of the response as it is linked to an immediate action (e.g., to reach for this item), shortening RTs to the central target. In contrast the passive object may show no effect or even slow down responses to the imperative stimulus, if the action to the passive object is suppressed as a competitor to the action to the object pair. The effect of an affordance between the objects (as in Riddoch et al., 2003; Roberts & Humphreys, 2010b) was assessed by contrasting responses to the imperative target when the objects were in “correct” and “incorrect” co-locations for a common action (see Figure 1). For example, take the correct co-location condition when the active objects were presented on the left side (left panel in Figure 1a). Here a right hand response to the target shape is aligned with the action afforded by the passive object (the bowl). Whether the orientation of the active object (the spoon) modulated this response was tested by comparing responses against a baseline (the incorrect co-location condition) when a right response was required and the orientation of the active object was incorrect for any interaction between the objects (left panel, Figure 1b; Experiment 1 and 4). Effects from the implied actions on the active object were assessed on left hand responses in this layout condition by comparing the correct co-location condition with another baseline condition. In this baseline (the incorrect co-location condition) the same response was required but the orientation of the passive object was manipulated (Figure 1c; Experiment 2). In Experiment 1, we tested effects of co-locating objects for action on the responses aligned with passive objects, and in Experiment 2 we assessed effects of implied actions in relation to the active object in each pair. If correctly positioning objects for action favourably modulates performance compatible with the passive objects, then any response congruent with the passive objects in the correct co-location condition in Experiment 1 should be faster than in the incorrect co-location condition, while this should be true for active objects in Experiment 2 if the implied action facilitates responses compatible with the active objects. On the other hand, if there is suppression of the response to either item when they are positioned for action, then corresponding responses to the imperative stimulus may be slower when the objects are in the correct relative to the incorrect co-locations for action.

In adopting this paradigm, the present study also went beyond others examining affordances with pairs of objects by having participants respond to an imperative stimulus that was independent of the objects being presented. In other studies participants have directly responded to the object pairs, in some cases using identification responses (Riddoch et al., 2003). It is possible that the affordance effect could have been facilitated by a top-down set to respond to related objects under these conditions. This seems less likely here, as the task set would involve only making a motor response to the imperative stimulus.

Experiment 3 contrasted the qualitative difference between the affordance effect of a single object with that of paired objects. In Experiment 3 we presented only active objects in otherwise the same experiment setting and examined whether the effects of paired-object affordance also occurs when the active objects were presented in isolation and followed by the imperative target. When the passive objects were replaced by empty space, will responses to the imperative target aligned with the empty space be inhibited when the active object was in the correct relative to the incorrect orientation as those aligned with the passive objects being inhibited in Experiment 1? This would be the case if the active object simply inhibited any other response. On the other hand, if inhibition depends on there being competition from the passive object, then there would not be inhibition of the action aligned with the empty space.

In Experiment 4 we aimed to replicate our findings while at the same time asking the question of how affordances are encoded, i.e. what kind of "action code" is activated (e.g. Bub, Masson, & Bukach, 2003; Ellis et al., 2007; Kiefer, Sim, Helbig, & Graf, 2011; Phillips & Ward, 2002; Tucker & Ellis, 2001)? Broadly speaking there are two options. On the one hand, the "action code" can be of a specific nature, specifying the effector, the direction of any action and the kinematic details (see Bub, Masson, & Bukach, 2003; Kiefer et al., 2011; Tucker & Ellis, 2001). On the other hand, it is also possible that any affordance activates categories of actions sharing certain, but not all features. This may have been implied when Gibson referred to objects being "lift-able" or "roll-able". Some evidence for this comes from the study by Phillips and Ward (2002). They showed that the affordance-based response compatibility effect (Tucker & Ellis, 1998) can be observed when the left and right responses are made by crossed hands or by feet (Phillips & Ward, 2002). They argued that graspable objects activate "relatively broadly defined categories of lateralized actions", e.g. actions on the left but not specific to the effector hand or types of grasp. Here we will extend this question to the paired-object scenario (Experiment 4). We borrowed a method from studies about the response compatibility effect of single objects by Cho and Proctor (2010). They had participants respond using button press responses with a single hand rather than assigning the responses bimanually. They still observed an effect of response compatibility between the orientation of the handle of the objects and the finger used for the response, consistent with an effect of response compatibility at an abstract level of response selection rather than specific to the parameters of the actual action to the stimulus. In the present study, we extended this design to displays with paired objects. We varied how participants responded – either using a bimanual response (Experiments 1 and 2), or a unimanual response (selecting the appropriate finger, Experiment 4).

Experiment 1: The effects of implied actions with active objects rotated as the baseline

The first experiment examined the effect of an action context (objects positioned correctly for action) on left and right hand responses to a central shape stimulus. On each trial two objects were presented, one active and one passive in the action, and the objects were positioned correctly or incorrectly for the interaction. The paired objects were followed by a central target, with the stimulus-onset asynchrony (SOA) being either 240 ms or 400 ms. There were two possible target shapes and participants were required to make a speeded choice response by pressing one of two keys with their left or right hands according to which shape was presented. The objects preceding the target shape was task-irrelevant. On half of the trials, the active object was presented on the left side of the pair (in the left visual field) and the passive object on the right. These positions were reversed for the other trials. When the objects were positioned incorrectly for action, the orientation of the active object was changed (see Figure 1a for an example of the correct co-location condition and Figure 1b for the incorrect co-location condition used in Experiment 1. The left panel shows when the active objects were presented on the left side of the object pair, and the right panel shows when they were presented on the right side). In the incorrect co-location condition, the active objects were always presented in orientations not affording any interaction with the passive objects. For responses aligned with the passive objects, the incorrect co-location condition served as a baseline for the correct co-location condition. The difference between these two conditions enables us to examine the effects of implied actions on responses aligned with passive objects, whose orientations and affordances were maintained across the conditions. In the correct co-location condition, the comparison between responses compatible with the active and passive objects illustrates the relative biases from the different objects when positioned correctly for action.

Materials and Methods

Participants

Thirty healthy volunteers (three males, mean age 19 years) from the University of Birmingham research participation scheme were recruited in Experiment 1. All participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received course credits for their time.

Another two groups of volunteers (twelve, four males, in each group, mean age 22 and 20 years respectively) from the University of Birmingham research participation scheme were asked to evaluate the stimuli used in Experiment 1 (See supplementary material for more details). All evaluation participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received course credit as compensation for their time.

Materials

The stimuli and the trial sequence were generated using Matlab7 (The MathWorks Inc., Natick, MA, USA) with Psychtoolbox 3. All stimuli were presented on a 17-in Samsung SyncMaster 793s (1280 × 1024 at 75 Hz) connected to a Windows XP computer. The stimuli consisted of 23 pairs of greyscale clip-art style images of objects on a rectangular white background. Each pair included an active object and a passive object routinely used together in an action (see Figure 1 for an example and Appendix A for a complete list of the object pairs used). Some stimuli appeared in more than one object pair, for instance a jug appeared in a jug-cup pair and a jug-glass pair. In total, 16 active objects and 15 passive objects were used as stimuli. The stimuli were rated by a separate group of evaluation participants regarding (a) whether the action relations between the objects were familiar and apparent, (b) whether, by changing orientation of the active objects in the incorrect co-location condition we effectively manipulated the implied actions between objects, and (c) whether the objects on the left and right side of the screen afford left- and right- hand responses respectively. A second group of participants evaluated the appropriateness of our assignment of active and passive objects, i.e. whether the participants considered our active objects as operating upon the passive objects. The results revealed that the stimuli fulfilled these criteria. The detailed description of the procedure and the results of the stimulus evaluation process can be found in supplementary material.

On each trial, line-drawings of a pair of objects were presented on the screen. On half of the trials (in the correct co-location condition), the objects were co-located appropriately for interaction. On the other half of the trials (the incorrect co-location condition), the active object was positioned in an orientation inappropriate to interact with the corresponding passive object. In the active-left condition, the active objects were presented on the left side of the screen, while the passive objects appeared on the right side. In the active-right condition, the whole presentation was horizontally flipped from the corresponding active-left presentation. All object images were presented on a white background (255, 255, 255 RGB). Each object image subtended 3.2°×3.2° of visual angle. The relative sizes of the objects within each pair matched their relative sizes in real life.

The other stimuli included a fixation cross subtending 0.8°×0.8° of visual angle and two response targets (a blue [0, 121, 212 RGB] triangle or a circular disk), both subtended 0.6°×0.6° of visual angle.

Procedure

Participants took part individually in Experiment 1, with their upper arms resting on the table and index fingers of both hands resting on the f and j keys respectively. The experiment consisted of one practice block and five experimental blocks. The practice block consisted of 40 trials, randomly assigned to different conditions. Each experimental block consisted of 128 trials following five warm-up trials. The experimental trials were evenly assigned to the different conditions and were presented in a pseudo-randomized order, with no more than three consecutive trials from the same condition. Each warm-up trial was randomly assigned to a condition. Several participants were required to repeat the practice block because they failed to meet the accuracy criteria (see below) in the first practice block. The accuracy criteria were the same for practice and formal blocks.

At the beginning of each trial, a fixation point was presented at the centre of the screen for 0.4 second. After this the fixation cross disappeared and an object pair appeared. After either 240ms or 400ms (SOA) a response target was presented at the centre of the screen (see Figure 2). The target and the object pair remained on the screen either until the participants made a response or a period of 1600 ms passed without response. Participants indicated whether the target was a triangle or a circle by using their left or right index finger to press the f or j key on a QWERTY keyboard. The stimulus–response mapping was counter-balanced across subjects.

The participants were required to respond as quickly and accurately as possible, and they were warned that a block would be repeated either if they missed the target, i.e. if no response were made within the allowed 1600 ms after the target onset, more than three times or if they pressed the wrong key more than three times within that block. Feedback was given immediately after an error.

Results and Discussion

Participants were highly accurate, with the average accuracy of each condition being between 97.8% and 99.6% (mean 98.8%, see Table 1). For data cleaning, RTs were initially trimmed to remove responses quicker than 100 ms. RTs more than 2.5 standard deviations from the mean of each participant were then discarded in a non-recursive manner. Discarded trials were fewer than 2% of the total trials. The same was done for Experiment 2 - 4.

The mean RTs for the participants were initially entered into an analysis of variance (ANOVA) with SOA (240 ms and 400 ms), co-location of objects (correct vs. incorrect for action), the layout of paired objects (active-left vs. active-right) and the response compatibility (compatible with the active vs. passive object) as within-subjects factors.

There was a main effect of SOA, F (1, 29) = 97.57, p < .001, η^2 = .77, with RTs in the 240 ms SOA condition longer than in the 400 ms SOA condition (MD = 15 ms). The main effect of co-location was significant, F (1, 29) = 7.10, p = .012, η^2 = .20, with responses in the correct co-location condition quicker than in the incorrect co-location condition (MD = 3 ms). The main effect of response compatibility was significant too, F (1, 29) = 16.62, p < .001, η^2 = .36, with responses compatible with the active objects quicker than those compatible with the passive objects (MD = 5 ms). The main effect of the layout of objects (correctly or incorrectly co-located for action) was not significant (F < 1). However, there was a significant interaction between the co-location factor and response compatibility, F (1, 29) = 8.10, p = .008, η^2 = .22. An analysis of the simple effects revealed that the interaction between the co-location and response compatibility was mainly driven by the slowing of responses congruent with the passive objects when the objects were correctly positioned for action, compared with when the objects were not correctly located for action (when the orientation of active object changed, F (1, 29) = 19.48, p < .001, η^2 = .40, MD = 6 ms). In contrast to this, there was no difference between responses aligned with active objects in the correct and the incorrect co-location conditions, F < 1 (see Figure 3). In addition, responses compatible with the active objects were quicker than those compatible with the passive objects when the objects were correctly co-located for action, F (1, 29) = 17.52, p < . 001, η^2 = .38, MD = 8 ms, but not when the objects were incorrectly co-located for action, F (1, 29) = 2.29, p = .141, η^2 = .07, MD = 2 ms.

The results of Experiment 1 suggest that (a) the presence of interacting active objects slows down responses compatible with the passive objects, and (b) when both objects were presented in an interacting co-location, the responses aligned with the active objects were quicker than those aligned with the passive objects. The second effect is in line with previous studies reporting differences in the processing of active and passive objects (Riddoch et al., 2003; Roberts & Humphreys, 2010a). The first effect suggests that responses aligned with the passive object (i.e. the affordance of the passive object) are inhibited, relative to when the passive object is in the same orientation but the pair of objects are not positioned correctly for action (due to the inappropriate orientation of the active object). That is, there was an inhibitory effect of implied actions on the responses aligned with the passive objects. We do not consider our results can be solely explained by an advantage for the active objects in the correct co-location condition without there also being an inhibitory influence on the passive objects, because otherwise there should not have been difference between responses aligned with the passive objects in the correct and the incorrect co-location conditions. To the best of our knowledge, this is the first time an inhibitory effect from implied between-object actions has been directly demonstrated in conditions of paired object affordance. The advantage for active objects over the passive objects and the co-existence of this effect with a suppression of the response to the passive objects is in line with the results of Ellis et al. (2007, see Introduction), but here we show a specific effect for action-implying object pairs.

The question remains open regarding whether the responses aligned with the active objects were also affected by implied between-object actions. One possibility is that, because the object context was irrelevant to the task, participants might have suppressed responses to both objects in the object pairs. However, because the orientation of the active objects changed across co-location conditions, Experiment 1 cannot provide strong evidence regarding whether an inhibitory effect from implied between-object actions also influences the active objects, or whether implied between-object actions selectively affect the passive objects. To solve this problem, in Experiment 2 we compared the responses aligned with the active objects between the correct and the incorrect co-location conditions while the orientation of the passive object was changed and the orientation of the active object was maintained. In this case, the effect of implied actions on responses aligned with the active objects can be examined without influence from their orientation being changed. We do not have a specific hypothesis regarding what will be the effects of action context on active objects. One proposal is that the implied actions between the objects selectively lead to inhibition of the affordance from passive objects. In this case, the responses aligned with the active objects in the correct co-location condition should not be inhibited in Experiment 2. Thus, compared with the incorrect co-location condition, responses aligned with the active objects should not be slower than those in the correct co-location condition. On the other hand, it is possible that the inhibitory effect of presenting the objects in the correct co-location is not selective and affects the active and passive objects equally, regardless of the functional significance of the active objects. Then, we should expect to find a similar inhibitory effect of the correct co-location on responses aligned with the active objects in Experiment 2.

Experiment 2: The Effects of Implied actions with Passive Objects Rotated as the Baseline.

Experiment 2 replicated Experiment 1 but with a baseline condition in which the passive rather than the active object was rotated.

Method

A new sample of thirty healthy volunteers (four males, mean age 19 years, range: 18-30 yrs) from the University of Birmingham research participation scheme was recruited in Experiment 2. All participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received course credit for their time.

The basic design of Experiment 2 was the same as Experiment 1, except that in the incorrect co-location condition the orientation of passive objects, rather than that of active objects, was manipulated (see Figure 1c).

The materials were based on the same stimulus pool as Experiment 1, but some object pairs were replaced or removed to exclude those passive objects without an obvious upright orientation (e.g. tennis ball, pepper). The final set included 16 object pairs (see Appendix B for a complete list of object pairs). The appropriateness of the materials was verified by independent evaluation (see supplementary materials for detailed report). In addition, the background color of the visual field was changed into light grey (200, 200, 200 RGB).

Results and Discussion

Participants were highly accurate, with the average accuracy of the different conditions being between 97.0% and 99.7% (mean 98.5%, see Table 2).

The RT data were initially entered into an analysis of variance (ANOVA) with SOA (240 ms vs.400 ms), co-location (correct vs. incorrect), object layout (active-left vs. passive-left) and response compatibility (with active objects vs. passive objects) as within-subject factors.

There was a main effect of SOA, F (1, 29) = 98.73, p < .001, η^2 = .77, with RTs in the 240 ms SOA condition longer than in the 400 ms SOA condition (MD = 17 ms). The main effect of response compatibility was significant, F (1, 29) = 64.30, p < .001, η^2 = .69, with responses congruent with active objects quicker than those congruent with passive objects (MD = 11 ms). None of the other main effects or interactions were significant (ps > 0.1, see Figure 4).

In this experiment responses aligned with the active objects were in all cases faster than those aligned with the passive object, as shown by the significant main effect of response compatibility. This replicates the findings from Experiment 1 when the objects were correctly co-located for action. The replication is not surprising and demonstrated the robustness of the advantage for the active objects, since the correct co-location conditions were the same in Experiment 1 and 2. However, in Experiment 2, the main effect of co-location did not reach significance, nor was this factor involved in any interaction. Therefore, there was no evidence for responses aligned with active objects being affected when the objects were correctly located for between-object action compared with the baseline when the passive object was rotated. These results highlight the difference between active and passive objects in terms of how the affordances evoked by each object are differently affected by a contextual object positioned in the correct location for interaction. The results of Experiment 2 suggest that responses aligned with the active object are not affected by an implied action with a passive object, with it making little difference when the contextual object (the passive object in this case) is in the correct orientation for action or not, in sharp contrast with the results of Experiment 1. The lack of inhibitory effect on the active objects ruled out the possibility that both objects were suppressed unselectively because they are task irrelevant.

Experiment 3: Compatibility effect of implied actions requires the presence of a passive object

Experiment 1 and 2 suggested that active objects dominate paired-object affordance, inhibiting actions linked to the passive objects. However, it is possible that the active objects might have produced the observed effects in Experiment 1 as single objects. For example, the response evoked by the active object may simply inhibit any other response irrespective of the presence of another stimulus. In this case the implied between-object actions and the presentation of the objects as a pair may have no influence on performance; responses to the imperative target might be slowed if it is simply incompatible with that evoked by the active target (note that in that case the response to the imperative target would have been compatible to the passive object in Experiment 1 and 2). To test this possibility, in Experiment 3, only an active object was presented on each trial, without another (passive) object. It should be noted that there are examples in the literature where similar configurations have revealed response modulations. For instance, Symes, Ellis, and Tucker (2005) showed that the orientation of an action-relevant part of an object (either pointing to left or to the right) presented on one side of the screen modulated responses aligned with the opposite (empty) side of the presentation. Hence in principle it is conceivable that the inhibition effect found in responses to the imperative stimulus in Experiments 1 and 2 also occurs even if the passive object is not present (in Experiment 3).

Methods

A new sample of thirty healthy volunteers (six males, mean age 19 years, range: 18-27 yrs) from the University of Birmingham research participation scheme was recruited in Experiment 3. All participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received course credit for their time.

The procedure for Experiment 3 was the same as for Experiment 1 except that only the active object in each pair was presented, while the space that was previously occupied by passive objects was left blank (see Appendix C for a complete list of objects used in Experiment 3). For the sake of consistency, in Experiment 3, we still name the condition correct co-location when the active objects were positioned as if interacting with an invisible passive object, in the same orientation as in the correct co-location condition in Experiment 1 (see Figure 5 for exemplars of the stimuli). Similarly, the incorrect co-location condition referred to when the active objects were presented in an orientation impossible to perform any action in the direction of the blank space, as in the incorrect co-location condition in Experiment 1.

Results and Discussion

Participants were highly accurate (range = 97.7% - 99.3%, Mean = 98.5%, see Table 3).

Mean RTs were calculated for each participant in each condition, and were entered into an analysis of variance (ANOVA) with SOA (240 ms and 400 ms), orientation (correct vs. incorrect co-location), the layout of objects (active-left vs. active-right) and the response compatibility (aligned with the active objects vs. with the empty space) as within-subjects factors.

There was a main effect of SOA, F (1, 29) = 209.64, p < .001, η^2 = 0.88, with RTs in the 240 ms SOA condition longer than in the 400 ms SOA condition (MD = 24 ms). The main effect of co-location was significant, F (1, 29) = 9.33, p = .005, η^2 = 0.24, with responses in the correct co-location condition quicker than in the incorrect co-location condition (MD = 3 ms). There was a significant interaction between the layout of the objects and response compatibility, F (1, 29) = 5.09, p = .032, η^2 = 0.15. The analysis of simple effects revealed that the interaction reflected that right-hand responses were generally quicker than left-hand responses. Responses aligned with the active objects were quicker when they were made by the right hand than when they were made by the left hand (p =.033, MD = 9 ms), and the same trend was significant for the responses aligned with the empty side (p =.047, MD = 9 ms).

More importantly, the interaction between co-location and response compatibility was not significant, F (1, 29) = 3.07, p =.090, η^2 = 0.10 (see Figure 6). Pairwise comparisons suggested that responses to imperative targets congruent with the empty space (replacing passive object) were not slowed down by the presence of an interacting active object (p = .44, MD = 1 ms). In addition, responses congruent with correctly orientated active objects were quicker than those congruent with the empty space (p =.021, MD = 5 ms).

The results of Experiment 3 did not show the inhibitory effect of implied between-object actions. Notably, RTs to an imperative target that would have been compatible with the passive object (which is replaced by empty space in the experiment) were not slowed when the passive object was absent. This suggests that competition for action selection between the active and passive objects is critical to observe the inhibition of any response. This effect is not produced by the affordance evoked by the active object alone (e.g., inhibiting all incompatible responses) but needs to have the passive object present. In addition to this we did find that responses compatible with the active objects were quicker than those aligned with the empty space replacing the passive objects. However this might have occurred because the onset of the active objects was beneficial as a spatial cue preceding the imperative target. One should be cautious to conclude that this effect derives from the same source as the quicker responses aligned with active objects relative to those aligned with passive objects/empty space in Experiments 1 and 3.

Experiment 4: A Test of Abstract Response Coding

Experiment 1 and 2 established the main features of the effects of implied actions on responses aligned with objects in action-related pairs, revealing evidence for the suppression of responses to passive objects and an advantage for active objects over passive objects when the objects are correctly co-located for action. A remaining question, though, is whether these effects reflect activation of specific motor responses to the stimuli or activation at a more abstract level. As noted earlier, this has previously been addressed in studies using single-objects by manipulating whether participants respond using two-choice unimanual or bimanual button-press actions (Cho & Proctor, 2010; Tucker & Ellis 1998). In Experiment 4, we evaluated this possibility by having participants respond to target shapes with one of two fingers on a single hand. Do the effects of implied between-object action remain?

Methods

A new sample of eighteen volunteers (five males, mean age 21 years, range: 18-35 yrs) from the University of Birmingham research participation scheme was recruited. All the participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received course credit for their time.

The basic design of Experiment 4 was the same of Experiment 1 except that the participants were required to use the index and middle finger of their right hands and the j and k keys. One finger response was assigned to one shape and the other to the other shape, with the finger-shape assignment counter-balanced across participants.

The materials used in Experiment 4 were the same of Experiment 1 except that the background color of the presentation was changed into light grey (200, 200, 200 RGB).

Results and Discussion

Participants were highly accurate, with the average accuracy of each condition falling between 97.2% and 99.6% (mean 98.7%, see Table 4).

The RT data were initially entered into an analysis of variance (ANOVA) with SOA (240 ms and 400 ms), object co-location (correct vs. incorrect), object layout (active-left vs. passive-left) and response compatibility (compatible with active object vs. with passive object) as within-subject factors. There was a main effect of SOA, F (1, 17) = 55.31, p < .001, η^2 = .77, with RTs in the 240 ms SOA condition longer than in the 400 ms SOA condition (MD = 20 ms). The main effect of response compatibility was significant, F (1, 17) = 7.60, p = .013, η^2 = .31, with responses congruent with the active objects quicker than those congruent with the passive objects (MD = 5 ms). There was a significant interaction between co-location and response compatibility, F (1, 17) = 21.59, p <.001, η^2 = .56. The analysis of the simple main effects revealed that the interaction between co-location and response compatibility was mainly driven by the different influence of co-location on responses congruent with the active and passive objects: responses congruent with the passive objects were slower in the correct co-location condition, compared with the incorrect co-location condition, $F(1,17) = 9.00$, $p = .008$, $\eta^2 = .35$, MD = 6 ms, but those congruent with the active objects were quicker, $F(1,17) = 7.23$, $p = .017$, $\eta^2 = .30$, MD = 8 ms. In addition, responses congruent with the active objects were quicker than those congruent with the passive objects only when the co-location of the objects was correct, $F(1,17) = 30.96$, $p < .001$, $\eta^2 = .65$, MD = 13 ms (see Figure 7), not when it was incorrect ($F < 1$).

The results of Experiment 4 replicated the results of Experiment 1: responses aligned with a passive object were slower when an active object was positioned to interact with it, compared with when the co-location of the objects was incorrect for action (active objects rotated). In addition, when both objects were positioned in the correct co-locations for action, the responses aligned with the active objects were quicker than those aligned with the passive objects. It is worth noticing that there was also an orientation effect for active objects, i.e. when the active objects were positioned correctly for action, responses were quicker than when the active objects were rotated and positioned incorrectly for action.

In conclusion, the similar effects of implied actions in Experiments 4 and 1 suggest that changing the task from a bi- into a uni-manual one does not alter the influence of the affordances evoked by paired objects, replicating the results in Experiment 1.

General Discussion

In this study we presented task-irrelevant paired objects which are typically used together in familiar actions. We manipulated the co-location of the objects in order to vary the implied actions within each object pair. We compared the responses aligned with each object and examined how the RTs were affected by the presence of an interacting object, i.e. when the objects were presented as a part of a visual scene implying a common action between the stimuli.

Two major features of the effects of implied between-object actions were established in Experiment 1 and replicated across experiments (Experiment 4). One was that the presence of an interacting active object slowed down responses compatible with passive objects. Second, when both objects were presented in the correct co-locations for interaction, responses congruent with active objects were quicker than those congruent with passive objects. In addition, the inhibitory effect from an interacting object was only observed on responses aligned with passive objects (Experiment 1), not on those aligned with active objects (Experiment 2). This indicates the robustness of the responses associated with active objects and the dominant role of the active objects in a given action relation. Further, the results of Experiment 3 suggested that despite the dominance of active objects, the effects of implied actions between objects cannot be solely attributed to them, as single objects. The presence of a passive object is also crucial to our findings. Moreover, the present study examined the nature of the effects of implied between-object actions and indicated that the effects in our task were not reduced by a mono-manual task (in Experiment 4). This last result suggests that the findings were mainly driven by compatibility between the abstract codes of the object affordance and the response.

Overall, our findings show that the implied action between paired objects affects participants' responses despite the fact that any such action is irrelevant to the task. Hence our findings suggest that an affordance for action between objects can be coded in an automatic manner. In addition to this, we provide critical new evidence for competition for action selection when objects interact. We discuss this evidence below.

Inhibitory effect of implied actions on responses congruent with the passive objects

The present study demonstrated for the first time an inhibitory effect of implied actions between object on responses aligned with passive objects. In addition, this inhibitory effect selectively affects passive objects (Experiment 1 and 2). We suggest that it is functionally important that responses are suppressed to objects that would be passive when two objects are used together in an action, so that the action to the passive object does not then compete with actions to the active objects in the pair. The consequence of this is that there is a slowing of responses to the passive objects in the correct co-location condition. In at least some previous studies (e.g. in the work with visual extinction patients, Riddoch et al., 2003), the detection of both active and passive objects has been shown to increase when an action context is present (Riddoch et. al., 2003). This contrasts with our results and might reflect the different stages of processing where effects emerge in different studies. In particular, studies with extinction have typically required identification of objects. Pairs of interacting objects may be selected as a single "perceptual unit" (Riddoch et al., 2003), which enables patients to report both objects despite their attentional limitations (which generate extinction). In the present study, however, the effects measure response activation – albeit at a relatively abstract level (Experiment 4) – and competition for action (and suppression of the passive item) may specifically be at the level of abstract response codes.

The inhibitory effect of action context on responses aligned with the passive objects here echoes previous reports of inhibitory processes in affordance-based effects with single objects. For instance, suppressive surround effects have been noted in compatibility tasks in which responses compatible with the handle orientation of a target object were even slower than incongruent responses when the orientation of the handle slightly differed from that of the preceding object (Loach, Frischen, Bruce, & Tsotsos, 2008). An inhibitory component has also been included in computational models of affordance selection, i.e. to select among multiple feasible actions afforded by the same object (this includes: the TRoPICALS model, Caligiore et al., 2013, the FARS model, Fagg & Arbib, 1998, and the Selective Attention for Action model, SAAM, Boehme & Heinke, 2009). An inhibitory neural pathway from the PFC, probably involving the basal ganglia (BG) and the supplementary motor cortex (SMC), to the premotor cortex (PMC), has been suggested as the neural basis of inhibitory control over affordance selection (for a review, see Thill et al., 2013). In addition, there is evidence of inhibitory processing in response selection. For instance, Eimer and Schlaghecken (1998) demonstrated active inhibition upon automatically activated responses sharing attributes with distractors. Other studies have shown that responses congruent with the affordance of a nearby distractor are slowed compared with responses incompatible with the distractor affordance, leading to a reversed compatibility effect (Ellis et al., 2007). The suppression of responses congruent with the non-target objects in Ellis et al.'s study (2007) and the passive objects in our study, might serve as a mechanism to ensure the efficient execution of the action most consistent with current action goal. The novel advance we present here is to show that inhibitory effects can be cued by not only the top-down intentional control and target selection, but also the action-related contextual factors in a visual scene, such as the presence of an implied action between objects.

Dominance of the active objects in implied actions

The other main result here was that responses aligned with active objects were quicker than responses aligned with passive objects in the correct co-location condition. This result is in line with the previous conclusion drawn from studies where a bias towards the active objects has been observed when objects are placed in an action context (e.g. Roberts & Humphreys, 2010a, 2011a). For instance, in their study of extinction, Riddoch et al. (2003) found that patients tended to report the active objects when objects were co-located for action, even when the active object was presented on the contralesional (usually extinguished) side. This advantage for active objects is also evident in studies with neurologically typical participants. For instance, in temporal order judgement tasks neurologically typical participants have an attentional bias towards the active object when it is positioned to interact with a passive object (Roberts & Humphreys, 2010a). The present study extents these findings and suggests a bottom-up source for this bias, not contingent on the task-set to respond to the objects present. Our study suggests that the active objects might generate stronger affordance-related codes and exerted a larger facilitative effect on responses sharing the same codes, compared with those responses sharing codes with the passive objects, in the correct co-location condition.

Even though both the inhibitory effects with passive objects and the facilitatory effect with active objects suggest differentiable impacts on active and passive objects from implied between-object actions, we would like to underline that the current study does not specifically suggest that the semantic knowledge of active and passive objects produced the effects. In contrast, we showed that the mere change of object orientation affected responses (the contrast between the correct and the incorrect co-location conditions). Since such change should not have affected semantic knowledge of objects, the observed effects are compatible with an affordance rather than a semantic account.

Evidence for abstract codes of paired-object affordance

The present study found that the effects of implied actions were not greatly reduced in monomanual task (Experiment 4), compared with the bimanual key-pressing task (Experiment 1). The lack of a response modality effect suggests that the implied actions do not activate action codes for a specific motor program. Instead, the implied actions result in the activation of action codes at a more abstract level for paired-object affordances.

As reviewed in the Introduction, it has been suggested that what is activated by visually presented graspable objects is a relatively broadly defined category of lateralized actions sharing the left-right feature of visual affordances (Phillips & Ward, 2002). According to this account, relative left-right codes are generated according to the action-related feature or affordance. When these codes overlap with the required responses, responses are faster and more accurate than when they do not. In our case, the observed effects might have been produced by compatibility between the automatic activation of the left-right codes of the responses and the automatically generated left-right codes of the implied action, which is biased towards the side of the active objects rather than passive objects in the correct co-location condition. In contrast to the abstract codes account, the affordance account would suggest that the specific actions afforded by objects are automatically "potentiated" (e.g. Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012; Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003; Tucker & Ellis, 1998).

The critical difference between these two accounts is that the affordance account predicts the activation of the motor program of the afforded action, while the spatial codes account does not. In Experiment 4, by changing the explicit task from a bimanual into a mono-manual one, we eliminated any compatibility effects between effector hands and the actions afforded by the objects. However, both the inhibitory effect of implied actions on passive objects (6 ms in Experiment 4 vs. 6 ms in Experiment 1), and the advantage for active objects, were still evident (13 ms in Experiment 4 vs. 8 ms in Experiment 1), suggesting the involvement of overlap between abstract codes in producing our results.

Together with the evidence of the involvement of relative spatial coding in compatibility effects with single objects (e.g. Cho & Proctor, 2010, 2011; Iani, Baroni, Pellicano, & Nicoletti, 2011) and on task-irrelevant motion information (Bosbach, Prinz, & Kerzel, 2005), our study adds new support to the notion that relative abstract left-right codes generated by the graspable objects, even when irrelevant to current task, affect responses to such objects (Cho & Proctor, 2010; Phillips & Ward, 2002). However, our results should not be taken as indicating that the effects of implied actions are immune from the influence of action intention. It has been reported that affordance-based action compatibility effects - elusive in left-right key-press tasks - can be observed in reaching and grasping tasks, which incorporate stronger action intention towards the objects compared to a key-pressing task (Bub & Masson, 2010). In the present paradigm, it is possible that action intention might also be able to increase the size of the effects observed here. It is worth noting, however, that the current sizes of effects are not outside the range of compatibility effects typically observed in “affordance” type experiments (Pellicano et al., 2010; Phillips & Ward, 2002; Symes, Ellis & Tucker, 2005, 2007; Tucker & Ellis, 1998). However, it would be interesting to examine performance when the action implied between the objects is explicit or task relevant, and when a response is directly required to the objects, rather than presenting the objects as an irrelevant context. Also, it will be beneficial to examine whether the relatively small effect of implied action will be increased by more realistic stimuli instead of the schematic object images used here.

Action relation, affordance selection, and scene perception

Our results also have implications for studies of affordance selection and scene perception.

As mentioned in the introduction part, previous theories of affordance selection have largely focused on the modulation from the decision making process or on an influence from irrelevant distractors on a central object (Cisek, 2007; Thill et al., 2013). However, a more typical, and probably of higher ecological value, challenge is to select the most appropriate action in a loosely structured scene in which the affordance of each object is constrained by their functional and spatial relation with other objects. For instance, when a cup is presented alone, it affords being grasped and moved actively for drinking, but it also affords being held passively to have tea poured into it in the context of an appropriately positioned teapot, in which situation the primary action afforded by the scene is the grasping and moving of the teapot. Our results suggested that such visual and spatial features about action between objects are capable of informing affordance selection. This notion echoes with existing report that the disturbance of configural features of an interacting object pair interfered the effect of action relation in reducing visual extinction (Riddoch et al., 2011). Moreover, our results suggested that such contextual information helps narrowing affordance selection to the affordance of the active objects, and presumably to the affordance associated with the interaction between objects.

Regarding scene perception, our findings are compatible with the argument that meaningful (functional) relations between objects are coded in the representation of a visual scene (Green & Hummel, 2006). Such representations serve to reduce competition for selection among visual objects (Riddoch et al., 2003) and modulate the distribution of attention and the speed of object identification (Roberts & Humphreys, 2011a, 2011b). In addition to these results, our study suggests that implied actions are extracted automatically from a given scene, and there is greater affordance-related activation for "active" objects in a scene along with affordance-related inhibition for objects not affording the primary action in the scene. The advantage for objects with higher action possibilities is consistent with eye tracking results showing that, when presented in a scene containing objects affording a sequence of action, the eyes of the user usually orient towards the next object in the action sequence immediately before the actual manipulation of the objects (Land & Mayhoe, 2001). Here potential actions between objects can serve as cues for action and may affect manual responses as well as attention distribution, facilitating further processing of the visual scene. This suggestion echoes with the view that there is a close interaction between object perception, attention and action planning (Gibson, 1979; Goodale & Humphrey, 1998; Humphreys, Yoon, et al., 2010), and that attention to the array of objects (and hence, object selection) can be strongly action-centred (Tipper, Lortie, & Baylis, 1992). Admittedly, the present study tested influence of implied actions in a rather simplified unnatural experimental setting. Further work is needed to examine whether the action-related influences we have observed operate in the more complex visual scenes more characteristic of real-world environment.

Conclusion

The current study extended previous works demonstrating the effect of action relations between objects on object identification in neuropsychological populations (Humphreys & Riddoch, 2001; Humphreys, Riddoch, Forti, & Ackroyd, 2004; Humphreys, Wulff, Yoon, & Riddoch, 2010; Riddoch et al., 2003) and healthy participants (Roberts & Humphreys, 2010a, 2010b, 2011a, 2011b). Our results illustrated that responses to different objects were modulated by the scene context in opposite ways – responses to objects active in the action being facilitated and responses to passive objects being suppressed. The work points to the competition between affordances of action related objects, and the importance of contextual information in affordance selection in multi-object visual scenes.

Captions for figures and tables

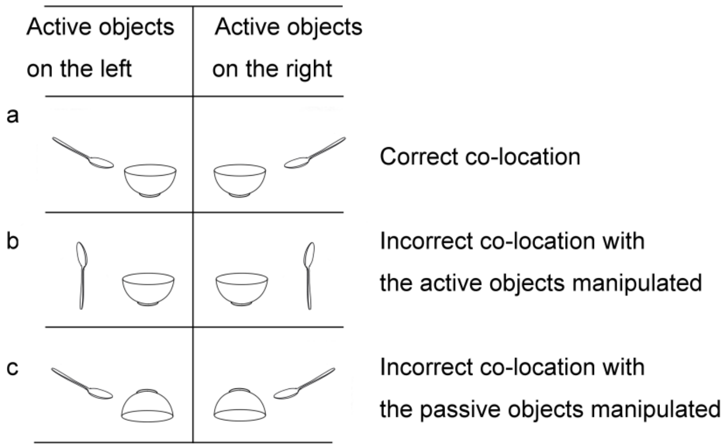

Figure 1. Example of the stimuli used in the experiments.

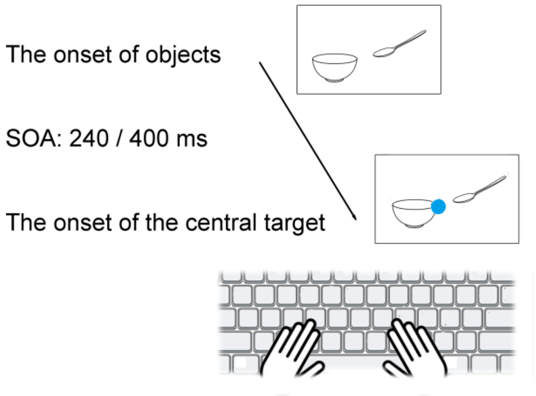

Figure 2. The procedure in Experiment 1. The participants were required to make speeded key-press responses with the left or right index finger, according to the shape of the central target (in display 2). The responses made by the hand on the same side with the active objects (right hand response in this figure) were considered congruent with the affordance of active objects and responses on the other side (left hand response in this figure) were congruent with the affordance of the passive objects.

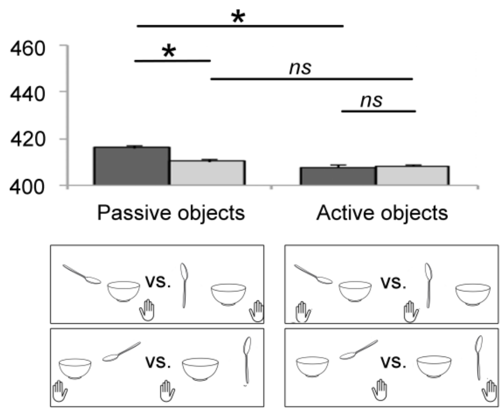

Figure 3. In Experiment 1, RTs of responses compatible with the passive objects were shorter in the incorrect co-location condition compared with the correct co-location condition (the black and grey bars on the left side). In the correct co-location condition, the mean RTs of responses compatible with the active objects were shorter than those compatible with the passive objects (the black bars). The error bars indicate the standard error of each condition following the method proposed by Cousineau (2005). The significance of pairwise comparisons is denoted on the figure (a = .05).

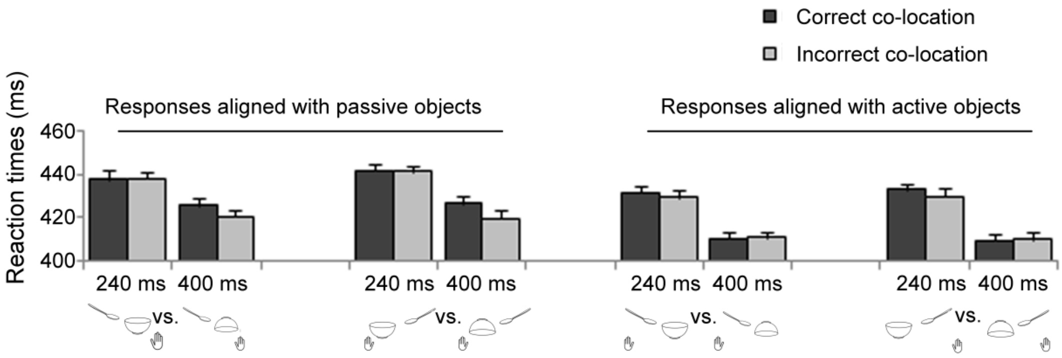

Figure 4. RTs in different conditions in Experiment 2.

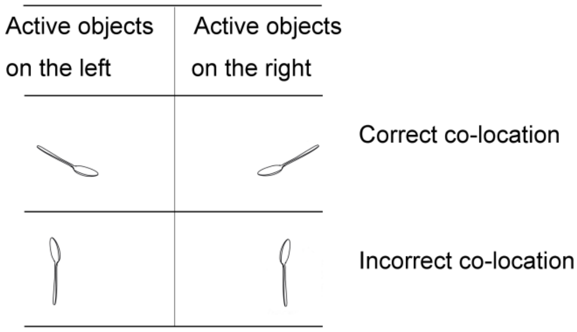

Figure 5. Exemplary stimuli in different conditions in Experiment 3.

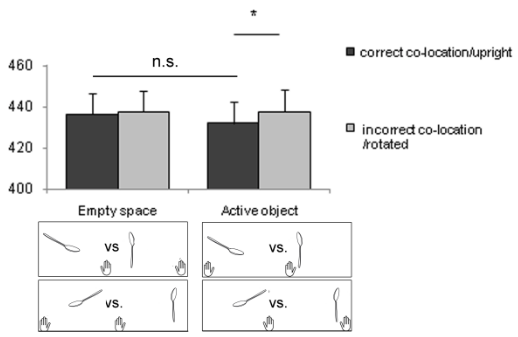

Figure 6. In Experiment 3, responses aligned with the active objects were quicker in the correct co-location condition than in the incorrect co-location condition, while the orientation of the active objects did not affect responses on the empty side. The error bars indicate the standard error of each condition following the method proposed by Cousineau (2005). The significance of pairwise comparisons is denoted on the figure (a = .05).

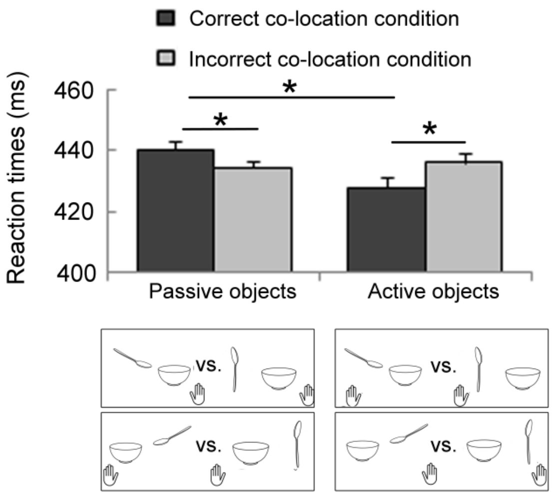

Figure 7. In Experiment 4, the mean RTs of responses compatible with the passive objects were longer in the correct relative to the incorrect co-location condition (the black and grey bars on the left side). In the correct co-location condition, RTs for responses compatible with the active objects were shorter than those compatible with the passive objects (the black bars). RTs compatible with the active objects were shorter in the correct than the incorrect co-location condition. The error bars indicate the standard error of each condition following method proposed by Cousineau (2005). The significance of pairwise comparisons is denoted on the figure (a = .05).

Table 1

Average accuracy and reaction times (RTs) of each condition in Experiment 1

Layout (active objects on the left or right)	Response compatibility (passive vs. active objects)	Accuracy	RTs (ms)
240 ms SOA			
Correct co-location			
Left	Passive	0.99	425
	Active	1.00	416
Right	Passive	0.99	424
	Active	0.99	415
Incorrect co-location			
Left	Passive	0.99	418
	Active	0.99	416
Right	Passive	0.99	418
	Active	0.99	415
400 ms SOA			
Correct co-location			
Left	Passive	0.98	403
	Active	0.99	399
Right	Passive	0.98	414
	Active	0.99	401
Incorrect co-location			
Left	Passive	0.98	403
	Active	0.99	401
Right	Passive	0.99	402
	Active	0.99	402

Table 2

Average accuracy and reaction times (RTs) of each condition in Experiment 2

Layout (active objects on the left or right)	Response compatibility (passive vs. active objects)	Accuracy	RTs (ms)
240 ms SOA			
Correct co-location			
Left	Passive	0.98	438
	Active	0.99	431
Right	Passive	0.99	442
	Active	0.99	433
Incorrect co-location			
Left	Passive	0.98	438
	Active	0.99	429
Right	Passive	0.99	441
	Active	0.99	430
400 ms SOA			
Correct co-location			
Left	Passive	0.98	426
	Active	0.99	410
Right	Passive	0.99	426
	Active	0.98	409
Incorrect co-location			
Left	Passive	0.97	420
	Active	0.99	411
Right	Passive	0.98	420
	Active	0.99	410

Table 3

Average accuracy and reaction times (RTs) of each condition in Experiment 3

SOA	Layout (active objects on the left or right)	Response compatibility (passive vs. active objects)	Accuracy	RTs (ms)
240 ms	Correct co-location			
	Left	Empty	.97	446
		Active	.99	448
	Right	Empty	.98	452
		Active	.99	440
	Incorrect co-location		.98	
	Left	Empty	.99	450
		Active	.99	452
	Right	Empty	.98	456
		Active	.99	446
400 ms	Correct co-location		.99	
	Left	Empty	.99	419
		Active	.98	425
	Right	Empty	.98	430
		Active	.99	415
	Incorrect co-location		.99	
	Left	Empty	.98	415
		Active	.97	432
	Right	Empty	.99	430
		Active	.98	421

Table 4

Average accuracy and reaction times (RTs) of each condition in Experiment 4

Layout (active objects on the left or right)	Response compatibility (passive vs. active objects)	Accuracy	RTs (ms)
240 ms SOA			
Correct co-location			
Left	Passive	0.99	457
	Active	0.99	443
Right	Passive	0.99	448
	Active	0.99	429
Incorrect co-location			
Left	Passive	0.99	445
	Active	0.99	447
Right	Passive	0.99	444
	Active	0.98	441
400 ms SOA			
Correct co-location			
Left	Passive	0.98	435
	Active	0.98	420
Right	Passive	0.99	428
	Active	0.97	408
Incorrect co-location			
Left	Passive	0.98	432
	Active	0.99	427
Right	Passive	0.98	422
	Active	1.00	417

References

Boehme, C., & Heinke, D. (2009). Modelling visual Affordances: The Selective Attention for Action Model (SAAM). In J. Mayor, N. Ruh, & K. Plunkett (Eds.), *Connectionist models of behaviour and cognition II* (pp. 129-140). London: World Scientific. (Proceedings of the 11th Neural Computation and Psychology Workshop (NCPW11), University of Oxford, UK, 16-18 July 2008.

Bosbach, S., Prinz, W., & Kerzel, D. (2005). Is direction position? Position-and direction-based correspondence effects in tasks with moving stimuli. *The Quarterly Journal of Experimental Psychology Section A*, *58*(3), 467-506. doi: 10.1080/02724980443000016

Bub, D. N., & Masson, M. E. (2010). Grasping beer mugs: on the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(2), 341-358. doi: 10.1037/a0017606

Bub, D. N., Masson, M. E., & Bukach, C. M. (2003). Gesturing and naming: the use of functional knowledge in object identification. *Psychological Sciences*, *14*, 467-472. doi: 10.1111/1467-9280.02455

Bub, D. N., Masson, M. E., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition*, *106*(1), 27-58. doi:10.1016/j.cognition.2006.12.010

Caligiore, D., Borghi, A. M., Parisi, D., Ellis, R., Cangelosi, A., & Baldassarre, G. (2013). How affordances associated with a distractor object affect compatibility effects: A study with the computational model TRoPICALS. *Psychological Research*, *77*(1), 7-19. doi: 10.1007/s00426-012-0424-1

Cho, D. T., & Proctor, R. W. (2010). The object-based Simon effect: Grasping affordance or relative location of the graspable part?. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(4), 853-861. doi:10.1037/a0019328

Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1485), 1585-1599. doi: 10.1098/rstb.2007.2054

Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience*, *33*, 269-298. doi: 10.1146/annurev.neuro.051508.135409

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology, 1*(1), 42-45. Retrieved from http://doe.concordia.ca/cslp/Downloads/PDF/Confidence%20intervals..art.pdf

Duncan, J., Humphreys, G., & Ward, R. (1997). Competitive brain activity in visual attention. *Current Opinion in Neurobiology*, *7*(2), 255-261. doi:10.1016/S0959-4388(97)80014-1

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(6), 1737-1747. doi:10.1037/0096-1523.24.6.1737

Ellis, R., Tucker, M., Symes, E., & Vainio, L. (2007). Does selecting one visual object from several require inhibition of the actions associated with nonselected objects?. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(3), 670-691. doi: 10.1037/0096-1523.33.3.670

Fagg, A. H., & Arbib, M. A. (1998). Modeling parietal–premotor interactions in primate control of grasping. *Neural Networks*, *11*(7-8), 1277-1303. doi: 10.1016/S0893-6080(98)00047-1

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Goodale, M. A., & Humphrey, G. K. (1998). The objects of action and perception. *Cognition*, *67*(1), 181-207. doi: 10.1016/S0010-0277(98)00017-1

Goslin, J., Dixon, T., Fischer, M. H., Cangelosi, A., & Ellis, R. (2012). Electrophysiological examination of embodiment in vision and action. *Psychological Science*, *23*(2), 152-157. doi: 10.1177/0956797611429578

Green, C., & Hummel, J. E. (2006). Familiar interacting object pairs are perceptually grouped. *Journal of Experimental Psychology: Human Perception and Performance, 32*(5), 1107-1119. doi: 10.1037/0096-1523.32.5.1107

Handy, T. C., Grafton, S. T., Shroff, N. M., Ketay, S., & Gazzaniga, M. S. (2003). Graspable objects grab attention when the potential for action is recognized. *Nature Neuroscience*, *6*(4), 421-427. doi:10.1038/nn1031

Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research*, *56*(4), 261-268. http://dx.doi.org/10.1037/0096-1523.25.3.688

Humphreys, G. W., & Riddoch, M. J. (2001). Detection by action: Neuropsychological evidence for action-defined templates in search. *Nature Neuroscience*, *4*(1), 84-88. doi: 10.1038/82940

Humphreys, G. W., Riddoch, M. J., Forti, S., & Ackroyd, K. (2004). Action influences spatial perception: Neuropsychological evidence. *Visual Cognition*,*11*(2-3), 401-427. doi: 10.1080/13506280344000310

Humphreys, G. W., Wulff, M., Yoon, E. Y., & Riddoch, M. J. (2010). Neuropsychological evidence for visual-and motor-based affordance: Effects of reference frame and object–hand congruence. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(3), 659-670. doi: 10.1037/a0019317

Humphreys, G. W., Yoon, E. Y., Kumar, S., Lestou, V., Kitadono, K., Roberts, K. L., & Riddoch, M. J. (2010). The interaction of attention and action: From seeing action to acting on perception. *British Journal of Psychology*, *101*(2), 185-206. doi: 10.1348/000712609X458927

Iani, C., Baroni, G., Pellicano, A., & Nicoletti, R. (2011). On the relationship between affordance and Simon effects: Are the effects really independent? *Journal of Cognitive Psychology*, *23*(1), 121-131. doi: 10.1080/20445911.2011.467251

Kiefer, M., Sim, E. J., Helbig, H. B., & Graf, M. (2011). Tracking the time course of action priming on object recognition: Evidence for fast and slow influences of action on perception. *Journal of Cognitive Neuroscience, 23*, 1864-1874. doi:10.1162/jocn.2010.21543

Kornblum, S., Stevens, G. T., Whipple, A., & Requin, J. (1999). The effects of irrelevant stimuli: 1. The time course of stimulus–stimulus and stimulus–response consistency effects with Stroop-like stimuli, Simon-like tasks, and their factorial combinations. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(3), 688-714. doi: 10.1007/BF00419656

Land, M. F., & Hayhoe, M. (2001). In what ways do eye movements contribute to everyday activities?. *Vision Research*, *41*(25), 3559-3565. doi: 10.1016/S0042-6989(01)00102-X

Loach, D., Frischen, A., Bruce, N., & Tsotsos, J. K. (2008). An attentional mechanism for selecting appropriate actions afforded by graspable objects. *Psychological Science*, *19*(12), 1253-1257. doi: 10.1111/j.1467-9280.2008.02234.x

Pavese, A., & Buxbaum, L. J. (2002). Action matters: The role of action plans and object affordances in selection for action. *Visual Cognition*, *9*(4-5), 559-590. doi: 10.1080/13506280143000584

Pellicano, A., Iani, C., Borghi, A. M., Rubichi, S., & Nicoletti, R. (2010). Simon-like and functional affordance effects with tools: The effects of object perceptual discrimination and object action state. *The Quarterly Journal of Experimental Psychology*, *63*(11), 2190-2201. doi: 10.1080/17470218.2010.486903

Phillips, J. C., & Ward, R. (2002). SR correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition*, *9*(4-5), 540-558. doi: 10.1080/13506280143000575

Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R. & Heafield, T.(1998). Visual affordances direct action. Neuropsychological evidence from manual interference. *Cognitive Neuropsychology, 15*, 645-684. doi: 10.1080/026432998381041

Riddoch, M. J., Humphreys, G. W., Edwards, S., Baker, T., & Willson, K. (2003). Seeing the action: neuropsychological evidence for action-based effects on object selection. *Nature Neuroscience, 6*(1), 82-89. doi:10.1038/nn984

Riddoch, M.J., Humphreys, G.W. & Price, C.J. (1989) Routes to action: Evidence from apraxia. *Cognitive Neuropsychology, 6*, 437-454. doi: 10.1080/02643298908253424

Roberts, K. L., & Humphreys, G. W. (2010a). The one that does, leads: action relations influence the perceived temporal order of graspable objects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(3), 776-780. doi: 10.1037/a0018739

Roberts, K. L., & Humphreys, G. W. (2010b). Action relationships concatenate representations of separate objects in the ventral visual system. *Neuroimage*, *52*(4), 1541-1548. doi: 10.1016/j.neuroimage.2010.05.044

Roberts, K. L., & Humphreys, G. W. (2011a). Action relations facilitate the identification of briefly-presented objects. *Attention, Perception, & Psychophysics*, *73*(2), 597-612. doi: 10.3758/s13414-010-0043-0

Roberts, K. L., & Humphreys, G. W. (2011b). Action-related objects influence the distribution of visuospatial attention. *The Quarterly Journal of Experimental Psychology*, *64*(4), 669-688. doi: 10.1080/17470218.2010.520086

Symes, E., Ellis, R., & Tucker, M. (2005). Dissociating object-based and space-based affordances. *Visual Cognition*, *12*(7), 1337-1361. doi: 10.1080/13506280444000445

Symes, E., Ellis, R., & Tucker, M. (2007). Visual object affordances: Object orientation. *Acta Psychologica*, *124*(2), 238-255. doi:10.1016/j.actpsy.2006.03.005

Thill, S., Caligiore, D., Borghi, A. M., Ziemke, T., & Baldassarre, G. (2013). Theories and computational models of affordance and mirror systems: an integrative review. *Neuroscience & Biobehavioral Reviews, 37*(3), 491-521. doi: 10.1016/j.neubiorev.2013.01.012

Tipper, S. P., Lortie, C. & Baylis, G. C., (1992). Selective reaching: evidence for action centered attention. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 891–905. doi: 10.1037/0096-1523.18.4.891

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 830-846. doi: 10.1037/0096-1523.24.3.830

Tucker, M. & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8* (6), 769-800. doi: 10.1080/13506280042000144

Yoon, E. Y., Riddoch, M. J., & Humphreys, G. W. (2010) The paired object affordance effect. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 812-824. doi: 10.1037/a0017175

Appendices

Appendix A

Stimuli used in Experiment 1 and 4

	Active Objects	Passive Objects
1	Screwdriver	Screw
2	Jug	Glass
3	Bottle	Glass
4	Jug	Cup
5	Kettle	Cup
6	Bottle	Cup
7	Jug	Bowl
8	Kettle	Bowl
9	Bottle	Bowl
10	Watering can	Plant
11	Saw	Wood
12	Axe	Wood
13	Hammer	Nail
14	Pliers	Nail
15	Spoon	Bowl
16	Baseball bat	Baseball
17	Table tennis bat	Ping pong ball
18	Tennis racket	Tennis ball
19	Badminton racket	Birdie
20	Knife	Tomato
21	Knife	Carrot
22	Knife	Pepper
23	Wrench	Nut

Appendix B

Stimuli used in Experiment 2

	Active objects	**Passive objects**
1	Screwdriver	Screw
2	Jug	Glass
3	Bottle	Glass
4	Jug	Cup
5	Whisk	Bowl
6	Bottle	Cup
7	Jug	Bowl
8	Brush	Dustpan
9	Bottle	Bowl
10	Spatula	Frying pan
11	Hammer	Nail
12	Opener	Bottle
13	Corkscrew	Bottle
14	Pliers	Nail
15	Spoon	Bowl
16	Ladle	Saucepan

Appendix C

Stimuli used in Experiment 3

	Active Objects
1	Screwdriver
2	Jug
3	Bottle
4	Jug
5	Kettle
6	Bottle
7	Jug
8	Kettle
9	Bottle
10	Watering Can
11	Saw
12	Axe
13	Hammer
14	Pliers
15	Spoon
16	Baseball Bat
17	Table Tennis Bat
18	Tennis Racket
19	Badminton Racket
20	Knife
21	Knife
22	Knife
23	Wrench