Implied between-object actions affect response selection without knowledge about object functionality

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Supp. A: Stimuli used in Experiment 1

	Active objects	Passive objects
1	screwdriver	cup
2	jug	Ping pong ball
3	bottle	tomato
4	jug	Tennis ball
5	Bottle	carrot
6	Jug	nut
7	Bottle	wood
8	Hammer	birdie
9	Pliers	baseball
10	Spoon	wood
11	Kettle	screw
12	Kettle	pepper
13	Watercan	nail
14	Saw	bowl
15	Axe	bowl
16	Baseball Bat	plant
17	Ping-Pong Bat	glass
18	Tennis racket	cup
19	Badminton Bat	bowl
20	Knife	nut
21	Knife	glass

22	Knife	nail
23	wrench	cup

Supp. B: Stimuli used in Experiment 2

	"Active" objects	Passive objects
1	glass	screw
2	glass	nail
3	glass	Ping pong ball
4	cup	screw
5	cup	nail
6	cup	Ping pong ball
7	frying pan	screw
8	Frying pan	nail
9	frying pan	Ping pong ball
10	pot	screw
11	pot	nail
12	pot	Ping pong ball
13	bowl	screw
14	bowl	nail
15	bowl	Ping pong ball
16	glass	nut
17	cup	nut
18	Frying pan	nut
19	pot	nut
20	bowl	nut
21	glass	birdie

22	cup	birdie
23	Frying pan	birdie
24	pot	birdie
25	bowl	birdie

Supp. C: Material evaluation

C.1 Methods

C.1.1 Participants

A group of volunteers (12, four males, mean age 20 years) from the University of Birmingham research participation scheme participated in the material evaluation for Experiment 1 and 2, and a separate sample of 12 participants (seven males, mean age 25 years) from Beijing Normal University evaluated the materials for Experiment 3. Each group evaluated the stimuli used in respective experiments, on a) the familiarity of each object pair, b) the effect of co-location manipulation and c) the affordance of each object, and d) the distinction between the active and the passive objects. All participants were right-handed and had normal or corrected-to-normal vision. Participants gave informed consent and received monetary compensation for their time.

C.1.2 Materials and Procedure

Respective participants evaluated 23 pairs of objects used in Experiment 1, 25 pairs used in Experiment 2 and 80 pairs used in Experiment 3 regarding the above-mentioned aspects.

The material-evaluation session contains 5 blocks. In each of the first four blocks each object pair was presented in four variations, and each variation was evaluated in one trial. The variations were generated by manipulating orthogonally the way of presentation (active-left and active-right) and the co-location (correct and incorrect). In this way the material evaluation replicated all the possible displays of the given pair. In each trial, the object pair was presented at exactly the same location and of the same size as they were in Experiment 1 and 2, and the questions were presented below the images. The participants were required to answer the questions on a scale. The object pair, the question and the choices remained on the screen until a response was made. In the fifth block, the object pairs were evaluated according to a fourth aspect, i.e. the distinction between the active and the passive objects in each object pair, to validate our assignment of active and passive objects in an object pair. The objects were presented always in the correct co-location (as if being used together to fulfilling certain action) in the fifth block. Consequently in the active-passive judgement block each object pair was presented only twice, once with the active object on the left and once on the right side of the screen.

In each block the participants evaluated all object pairs and their variations according to the same question. The sequence of the questions was constant, but the sequence of object pairs within each block varied across blocks and participants.

The five questions served four main purposes:

a. **Familiarity of the action relation** Regarding whether the objects in each pair are typically involved in certain action relation, and whether the action relations between objects were recognized in the incorrect co-location condition:

   Are these objects typically used together?

   This question was for Block 1. The associated five-point scale is 1: definitely no; 2: maybe not; 3: not sure; 4: maybe yes; 5: definitely yes.

b. **The effect of co-location manipulation** Regarding whether the co-location of objects is appropriate for an implied action in the correct co-location condition but not in the incorrect co-location condition:

   Are these objects appeared to be being currently used together? Or, are they positioned properly or likely to be used together?

   This question was for Block 2. The associated five-point scale is 1: definitely no; 2: maybe not; 3: not sure; 4: maybe yes; 5: definitely yes.

c. **Object affordance** Regarding whether the assumption is valid that objects presented on the left side affords left-hand responses while objects presented on the right side affords right-hand responses:

   When the pair of objects are located in the way they are currently located on the screen, and you are going to use them together, which hand are you going to use to handle the object on the right side of the screen?

   When the pair of objects are located in the way they are located on the screen, and you are going to use them together, which hand are you going to use if you are going to handle the object on the left side of the screen?

   These two questions were for Block 3 and 4 respectively. The associated five-point scale is 1: definitely left hand; 2: not sure, but more likely left hand than right hand; 3: equally possible with either hand; 4: not sure, but more likely right hand; 5: definitely right hand.

d. **Distinction between active and passive objects** regarding which object in each pair was active. The question was presented as:

   When the pair of objects are located in the way they are located on the screen, and you are going to use them together, how will these two objects interact? Please press 1

if the object on the left hand side is going to be used upon the right one, and press 2 if the right object is going to be used upon the left one.

This question was for Block 5. The associated scale is 1: left upon right; 2: right upon left.

C.2 Results

The ratings of materials used in each experiment were analysed and reported separately.

The materials of Experiment 1 (active-passive object pairs which do not typically interact with each other)

Familiarity of action relation Objects in each pair were not evaluated as typically involved in any action. The absence of action relation persisted in the incorrect co-location condition. In response to the question "*Are these objects typically used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 1.44, *SD* = 0.28; for object pairs incorrectly co-located, the mean response was 1.41, *SD* = 0.31. Wilcoxon Signed Rank test revealed that the median of both ratings were significantly different from the mid-point, *p*s = 0.002, and their median values did not differ from each other (*p* = 0.66). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Effect of manipulation of co-location The manipulation of implied actions by changing the co-location of objects was efficient. Object pairs positioned suitable to be used together still gave a higher impression of being used together compared to the pairs in which the orientation of active objects were manipulated (in the incorrect co-location condition). In response to the question "*Are these objects appeared to be being currently used together? Or, are they positioned properly or likely to be used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 3.46, *SD* = 1.02; for the object pairs incorrectly co-located, the mean response was 1.54, *SD* = 0.40. Wilcoxon Signed Rank test revealed that the median of ratings was significantly different from the mid-point in the incorrect co-location condition, *p* = 0.002, but not in the correct co-location condition (*p* = 0.002), towards the "no" direction. The median values of these two conditions differed significantly from each other, *p* = 0.002, with responses in the correct co-location condition biased more to the "yes" direction compared to the incorrect co-location. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Object affordance The association between object location and object affordance was evident. The objects presented on the left side afforded left-hand responses while objects presented on the right side afforded right-hand responses. In response to the question "*When the pair of objects are located in the way they are currently located on the screen, and you are going to use them together, which hand are you going to use to handle the object on the right side of the screen?*" on a five-point scale ranging from "*1: definitely left" to "5: definitely right"*, the mean response to the correctly co-located objects on the right side was 3.73, *SD* = 0.64, the ones on the left side 2.86, *SD* = 0.98; for the object pairs incorrectly co-located, the mean response to the objects on the right side was 3.53, *SD* = 0.53, for the ones on the left side the mean was 3.00, *SD* = 0.89. Though the mean values suggested that participants tended to handle the right objects with the right hand and the left objects the left hand, Wilcoxon Signed Rank test revealed that only the ratings for the right objects significantly differed from the mid-point, in both the correct co-location condition and the incorrect co-location condition (*p*s = 0.003) while responses for the objects on the left side did not differ from the midpoint in both the correct and the incorrect co-location conditions, *p*s > .05. This might reflect the general preference of the right hand over the left hand among our right-handed participants. However, paired-sample Wilcoxon Signed Rank test revealed significant difference between the rating for the left and the right objects in the correct co-location condition, *p* = 0.002, but not in the incorrect co-location condition, *p* = 0.12. Paired-sample Wilcoxon Signed Rank test further showed that the manipulation of action relation did not significantly affect the inclination of handling objects with the hand corresponding to its location on the screen (*p*s > .11). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Active-passive distinction The active-passive distinction between objects was evident. When the designed active objects were presented on the left side the participants tended to report that the left objects were active, while for the passive-active object pairs the participants tended to report that the right objects were active. In response to the question "*When the pair of objects are located in the way they are located on the screen, and you are going to use them together, how will these two objects interact? Please press 1 if the object on the left hand side is going to be used upon the right, and press 2 if the right object is going to be used upon the left one.*", the mean response to the active-passive object pairs was 1.06, *SD* = 0.06, the passive-active objects 1.96, *SD* = 0.04. Wilcoxon Signed Rank test revealed that both ratings significantly differed from the mid-point, *p*s = .002, and that the difference between ratings for the active-passive and the passive-active pairs was significant, *p* = .002. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

The materials of Experiment 2 (pairs of passive objects)

Familiarity of action relation Objects in each pair were not evaluated as typically involved in the same action regardless of their co-location. In response to the question "*Are these objects typically used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 1.17, *SD* = 0.35; for object pairs incorrectly co-located, the mean response was 1.18, *SD* = 0.33. Wilcoxon Signed Rank test revealed that the median of both ratings were significantly different from the mid-point, *p*s = 0.002, towards the "No" end, and that the ratings for these two conditions did not differ significantly from each other, *p* = 0.46. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

As stated in the main part of the manuscript, we divided the object pairs according to whether the "active" objects have a handle. The results of Wilcoxon Signed Rank test showed that the absence of action relation was true in both the with-handle and without-handle object pairs; ratings were significantly different from the mid-point regardless of co-location for both the objects with and without handles (*p*s = 0.002), towards the "No" end, and co-location did not affect the median of the ratings for both kinds of object pairs (*p*s > 0.1). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Effect of manipulation of co-location The appropriateness of the co-location for serving the common action remained low regardless of the orientation of the active objects. In response to the question "*Are these objects appeared to be being currently used together? Or, are they positioned properly or likely to be used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 2.20, *SD* = 0.66; for object pairs incorrectly co-located, the mean response was 1.97, *SD* = 0.51. Wilcoxon Signed Rank test revealed that the median of ratings in both the correct, *p* = .005, and the incorrect, *p* = .002, co-location conditions significantly diverted from the mid-point, with the objects being judged not currently interacting, and that the ratings for these two conditions did not differ significantly from each other, *p* = .51. Parametric analysis (single and paired sample *t* tests) reported the same statistical conclusions.

To examine whether the same pattern existed for pairs with with-handle "active" objects and without-handle "active" objects, we divided the ratings of the two kinds of object pairs. The results of Wilcoxon Signed Rank test showed that the absence of action relation was true in both the with-handle and without-handle object pairs; ratings were significantly different from the mid-point regardless of co-location for both the objects with and without

handles (*p*s < 0.028), towards the “No” end, and co-location did not affect the median of the ratings for both kinds of object pairs (*p*s > 0.1). Further, the with-handle object pairs were perceived more likely to be interacting than those with a without-handle “active” object in both correct ($p = 0.015$) and incorrect ($p = 0.004$) co-location conditions. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Object affordance The association between object location and its affordance was evident. The objects presented on the left side afforded left-hand responses while objects presented on the right side right-hand responses. In response to the question “*When the pair of objects are located in the way they are currently located on the screen, and you are going to use them together, which hand are you going to use to handle the object on the right side of the screen?*” on a five-point scale ranging from “*1: definitely left” to “5: definitely right”*, the mean response to the correctly co-located objects on the right was 3.47, *SD* = 0.66, the ones on the left side 2.73, *SD* = 0.77; for object pairs incorrectly co-located, the mean response to the objects on the right side was 3.32, *SD* = 0.53, for the ones on the left side 2.70, *SD* = 0.74. Though the mean values suggested that participants tended to handle the right objects with their right hands while the left objects the left hands, Wilcoxon Signed Rank test revealed that only the ratings for the objects presented on the right in the correct co-location condition ($p = 0.056$) and those on the right ($p = 0.047$) and on the left ($p = 0.050$) in the incorrect co-location conditions significantly or margninally significantly differed from midpoint, while the ratings for objects on the left side in the correct co-location condition did not significantly divert from the mid-point ($p = 0.12$). This might reflect the general preference of the right hand over the left hand among our right-handed participants. However, paired-sample Wilcoxon Signed Rank test revealed significant difference between the ratings for left and right objects in both the correct co-location condition, $p = .008$, and the incorrect co-location condition, $p = .008$, but rotating the “active” objects did not significantly affect the inclination of handling objects with the hand corresponding to its location on the screen (*p*s > .05). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions except that in one-sample *t* test the difference between mid-point and the rating median for objects presented on the right in the correct co-location conditions reached significant ($p = 0.033$) and that between mid-point and median rating for objects presented on the left in incorrect co-location condition reduced from significant to marginally significant ($p = 0.058$).

To examine whether the same pattern existed for the object pairs with with-handle “active” objects and without-handle “active” objects, we divided the ratings of the two kinds of object pairs. One-sample Wilcoxon Signed Rank test revealed that the median ratings diverted from the mid-point for objects on both the left and the right when the object pairs

have a handle, as well as for the objects on the right in pairs without handle (*p*s < 0.028), but not for objects on the left when the object pairs did not have a handle. This may suggest that when there is no handle, the responses were more affected by a general inclination of handling objects with the dominant hand, the right hand for our right handed participants. Still, paired-sample Wilcoxon signed rank test revealed that the response were different to the objects on the left and on the right in both object pairs with (p = 0.002) and without (p = 0.010) handles, confirming the assumed affordance of objects in conditions of Experiment 2. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions except that median response for the objects on the right in pairs without handle was also different from the mid-point in parametric analysis.

Active-passive distinction The participants could not distinguish the "active" objects from the passive objects. In response to the question "*When the pair of objects are located in the way they are located on the screen, and you are going to use them together, how will these two objects interact? Please press 1 if the object on the left hand side is going to be used upon the right, and press 2 if the right object is going to be used upon the left one.*", the mean response to the active-passive object pairs was 1.48, SD = 0.30, the passive-active pairs 1.48, SD = 0.32. In addition, Wilcoxon Signed Rank test revealed that neither of the ratings significantly differed from the mid-point, *p*s >.05, and that the difference between the ratings for the active-passive and the passive-active pairs was not significant (p > .05). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Further analysis divided object pairs in terms of whether the "active" object in the pair has a handle. Wilcoxon Signed Rank test suggested that median responses for neither the active-passive nor the passive-active object pairs differed from mid-point, regardless of the "handle-ness" of object pairs, *p*s > 0.3, and that the median responses did not differ between the active-passive and the passive-active object pairs regardless of the "handleness" of the object pair, *p*s > 0.3, and that the "handleness" of the object pair did not affect median responses to either the active-passive and the passive-active object pairs (*p*s > 0.09). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

The materials of Experiment 3 (pairs of passive objects)

Eighty pairs of objects were constructed for Experiment 3, by combining five arbitrary shapes with each of the four handles to form 20 active objects, and pairing each of the novel active objects with 4 passive objects.

Familiarity of action relation Objects in each pair were not evaluated as typically involved in the same action regardless of their co-location. In response to the question "*Are these objects typically used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 2.17, *SD* = 0.47; for object pairs incorrectly co-located, the mean response was 2.12, *SD* = 0.46. Wilcoxon Signed Rank test revealed that the median of both ratings were significantly different from the mid-point, *p*s < 0.02, towards the "No" end, and that the ratings for these two conditions did not differ significantly from each other, *p* = 0.37. Parametric analysis (single and paired sample *t* tests) revealed the same statistical conclusions.

Effect of manipulation of co-location The appropriateness of the co-location for serving the common action remained low regardless of the orientation of the active objects. In response to the question "*Are these objects appeared to be being currently used together? Or, are they positioned properly or likely to be used together?*" on a five-point scale ranging from "*1: definitely No*" to "*5: definitely Yes*", the mean response to the correctly co-located object pairs was 2.96, *SD* = 0.67; for object pairs incorrectly co-located, the mean response was 2.57, *SD* = 0.51. Wilcoxon Signed Rank test revealed that the median of ratings for the incorrect co-location condition significantly diverted from the mid-point, *p* = 0.010, towards the "No" end, but the rating for the correct co-location condition did not, *p* = 0.84, and that the ratings for the correct co-location condition were higher, i.e. more likely to be currently interacting, than rating for the incorrect co-location condition, *p* = 0.041. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Object affordance The association between object location and its affordance was evident. The objects presented on the left side afforded left-hand responses while objects presented on the right side right-hand responses. In response to the question "*When the pair of objects are located in the way they are currently located on the screen, and you are going to use them together, which hand are you going to use to handle the object on the right side of the screen?*" on a five-point scale ranging from "*1: definitely left" to "5: definitely right"*, the mean response to the correctly co-located objects on the right was 3.53, *SD* = 0.69, the ones on the left side 3.03, *SD* = 0.44; for object pairs incorrectly co-located, the mean response to the objects on the right side was 3.54, *SD* = 0.69, for the ones on the left side 3.17, *SD* = 0.50. Wilcoxon Signed Rank test indicated that only the rating for the objects on the right side in the correct co-location condition (*p* = 0.033) as well as in the incorrect co-location condition (*p* = 0.037) significantly differed from midpoint, while the ratings for objects on the left side did not significantly divert from the mid-point (*p*s > 0.6). This might reflect the general preference of the right hand over the left hand among our right-handed participants. However, paired-sample Wilcoxon Signed Rank test revealed significant difference between

the ratings for the left and the right objects in both the correct co-location condition, $p = .023$, and the incorrect co-location condition, $p = .050$, suggested that participants tended to handle the right objects with their right hands while the left objects the left hands. Paired-sample Wilcoxon Signed Rank test further suggested that rotating the “active” objects did not significantly affect the inclination of handling objects with the hand corresponding to its location on the screen (ps > .12). Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

Active-passive distinction The participants could distinguish the novel active objects from the passive objects. In response to the question “*When the pair of objects are located in the way they are located on the screen, and you are going to use them together, how will these two objects interact? Please press 1 if the object on the left hand side is going to be used upon the right, and press 2 if the right object is going to be used upon the left one*.”, the mean response to the active-passive object pairs was 1.21, SD = 0.27, the passive-active pairs 1.80, SD = 0.28. In addition, one-sample Wilcoxon Signed Rank test suggested that the ratings significantly differed from the mid-point, when the active objects was presented on the right side, $p = .009$, biasing towards the right side, as well as when the active objects were presented on the left side, $p = 0.012$, biasing towards the left side, showing a preference towards the novel active objects. Also, paired-sample Wilcoxon Signed Rank test revealed that the difference between the ratings for active-passive and passive-active pairs was significant, $p = .011$. Parametric analysis (single and paired sample *t* tests) supported the same statistical conclusions.

C.3 Discussion

The results of material evaluation confirmed that the materials were appropriate for our experimental design. In summary (See also table Supp.C), the results reflected that the participants did not consider the stimuli in any of the three experiments as typically involved in any action, i.e. not carrying any established action relation. The results also support the basic assumption of our paradigm, that presenting objects on the left affords left responses and on the right side right responses. Further, the results suggested that regardless of co-location, there was no reportable implication of between-object actions across experiments, even when the objects were positioned mimicking the co-location of functionally related objects in interaction, i.e. in the correct co-location condition. This finding is consistent with our intention of pairing functionally irrelevant object pairs. For Experiment 1 and 3, the implied between-object actions were ambiguous in the correct co-location condition, and reliably absent in the incorrect co-location condition, suggesting that the impact of co-location manipulation may also exist on subjective reports and can be observed even when

the implication was already very weak. In Experiment 2, the participants did not consider that there was any interaction between objects in either co-location condition. These findings are in line with the aim of the experiment as it deliberately paired functionally irrelevant objects which typically play passive roles in between-object actions. The difference between Experiment 2 and the other two experiments is consistent with the finding that participants can correctly differentiate the active from the passive objects in Experiment 1 & 3 even though they did not report any reliable implied interaction between objects, but cannot differentiate the functional roles of objects in Experiment 2. It would be interesting for future study to examine whether the existing passive functional role of both objects (as in Experiment 2) prevents a reportable implication of between-object action to a larger extent than the mere absence of functional knowledge (such as the novel objects in Experiment 3).

Table Supp. C Results summary of material evaluation results

	Experiment 1: Functionally irrelevant active-passive object pairs	Experiment 2: Functionally irrelevant passive-passive object pairs	Experiment 3: Novel object-passive object pairs
Familiarity of the action relation	No	No	No
The effect of co-location manipulation	Correct and incorrect co-locations indicate interaction differently	Neither correct nor incorrect co-location condition indicates interaction	Correct and incorrect co-locations indicate interaction differently
Object affordance	Right objects are significantly different from the left objects, biasing towards the right.	Right objects are significantly different from the left objects, biasing towards the right.	Right objects are significantly different from the left objects, biasing towards the right.
Distinction between active and passive objects	Participants can differentiate active and passive objects in 2AFC	Participants do not differentiate the objects assigned as active objects from those not	Participants can differentiate the novel active object from the passive objects in 2AFC

Supp. D: Stimuli used in Experiment 3