Atten Percept Psychophys (2014) 76:214–229
DOI 10.3758/s13414-013-0565-3

The contextual action relationship between a tool and its action recipient modulates their joint perception

Nicolas A. McNair · Irina M. Harris

Published online: 23 October 2013

Abstract Facilitatory effects have been noted between tools and the objects that they act upon (their "action recipients") across several paradigms. However, it has not been convincingly established that the motor system is directly involved in the joint visual processing of these object pairings. Here, we used the attentional blink (AB) paradigm to demonstrate privileged access to perceptual awareness for tool–action recipient object pairs and to investigate how motor affordances modulate their joint processing. We demonstrated a reduction in the size of the AB that was greater for congruent tool–action recipient pairings (e.g., hammer–nail) than for incongruent pairings (e.g., scissors–nail). Moreover, the AB was reduced only when action recipients followed their associated tool in the temporal sequence, but not when this order was reversed. Importantly, we also found that the effect was sensitive to manipulations of the motor congruence between the tool and the action recipient. First, we observed a greater reduction in the AB when the tool and action recipient were correctly aligned for action than when the tool was rotated to face away from the action recipient. Second, presenting a different tool as a distractor between the tool and action recipient target objects removed any benefit seen for congruent pairings. This was likely due to interference from the motor properties of the distractor tool that disrupted the motor synergy between the congruent tool and action recipient targets. Overall, these findings demonstrate that the contextual motoric relationship between tools and their action recipients facilitates their visual encoding and access to perceptual awareness.

Keywords Tools · Action recipients · RSVP · Attentional blink

The use of tools entails not only negotiating the spatial and mechanical relationship between the hand and the tool, but also that between the tool and the object that it acts on—its "action recipient." This issue has been largely ignored in research on tool use, until more recent evidence has suggested that action recipients exert considerable influence on the representations of their associated tools. One line of evidence comes from patients with impairments in tool–use, who typically perform better when the tool's action recipient is present to be acted upon. For example, patients with apraxia have difficulty demonstrating the typical use of a tool in isolation, but not when also provided with its action recipient to act on (Osiurak et al., 2008, Osiurak, Jarry, & Le Gall, 2011). Some research has also shown that the relationship between these action–object pairings may influence not only our motor actions with tools but also their visual processing. Riddoch and colleagues have conducted a number of such investigations in patients with visual extinction (e.g., Riddoch, Humphreys, Edwards, Baker, & Wilson, 2003). Patients with this disorder, which typically follows lesions affecting the parietal lobe or the temporo-parieto-occipital junction, can readily detect and identify single objects presented in either their left or right visual fields. However, if two objects are presented simultaneously, one in each visual field, they often only perceive one of them—typically with a bias to the ipsilesional visual field. This is generally thought to arise from attentional competition between the objects, with the contralesional object being "extinguished" from awareness by the object on the ipsilesional side. In a series of studies, patients with extinction were presented with pairs of

N. A. McNair · I. M. Harris
School of Psychology, University of Sydney, Sydney, New South Wales, Australia

I. M. Harris
e-mail: irina.harris@sydney.edu.au

N. A. McNair (✉)
School of Psychology, Plymouth University, Drake Circus, Plymouth PL4 8AA, Devon, UK
e-mail: nicolasmcnair@gmail.com

objects that shared an action relationship (e.g., a corkscrew and a bottle of wine). Riddoch and colleagues demonstrated that the patients were considerably better at detecting both objects when they were positioned as if they were acting together. For example, identification performance was higher for bottle–corkscrew object pairs when the corkscrew pointed at the top of the bottle than when it pointed at the bottom of the bottle. These effects were not observed for associatively related, but not functionally related, action objects (e.g., a spoon and fork), nor when using words instead of pictures, indicating that this is not due to the semantic relatedness of tools and action recipients. Instead, Humphreys and Riddoch (2007) have suggested that tool and action recipient object pairs may form "perceptual units" comparable to the bottom-up grouping of object features or objects into perceptual "wholes" under Gestalt-like principles. These perceptual units can then be attended to as single object by the visual system. The formation of such perceptual units might be achieved through repeated experience with the relative spatial (i.e., positioning) and temporal (i.e., movement) co-occurrence of their constituent objects. This would include sensitivity to the correct orientation of the tool with respect to the action recipient, as observed in extinction patients, since we more often encounter these object pairs aligned in such a manner.

Despite the fact that action–object pairs appear to be processed in an integrated fashion by the visual system, it is unclear whether the motor system is directly involved in this integration. The effects could arise purely from our visual familiarity with these co-occurring objects (Humphreys & Riddoch, 2007). However, some evidence indicates that such perceptual units may even be able to be formed transiently, through our familiarity with more abstracted action principles. Riddoch et al. (2006) presented extinction patients with object pairs that formed unfamiliar, but still plausible, action relationships. For example, a wine bottle appearing to pour into a bucket. The patients showed an increased ability to attend to both objects, relative to an unfamiliar and motorically implausible pairing (such as a wine bottle pointed toward a tennis ball), although not as much as for familiar and plausible pairings (a wine bottle pointed toward a glass). Both motorically plausible pairings also elicited better performance when the object pairs were positioned for action (e.g., the wine bottle pouring) than when they were positioned side by side. This was not found for the unfamiliar, implausible object pairs. Thus, at least initially, it appears as though our understanding of the potential action relationship between two objects does influence their visual processing (or at least their access to perceptual awareness). This would imply a direct involvement of the motor system on such processing. Yet, such findings might still be attributable to the degree of visual similarity between the familiar and unfamiliar (but plausible) action recipients. On the basis of our experience with such objects, a bucket arguably shares a more similar visual structure to a glass than does a tennis ball. The fact that performance was higher when objects were positioned for action may be ascribed to the spatial *and* temporal co-occurrence of such pairings, in contrast to the purely spatial familiarity when positioned beside each other. Therefore, it remains unresolved to what extent the motor system is involved in such visual processing of objects.

In the present study we asked whether similar evidence for a privileged access to perceptual awareness for action object pairs, as that seen in extinction patients, can be obtained in healthy participants. To do this, we utilized the "attentional blink" phenomenon (AB; Raymond, Shapiro, & Arnell, 1992), which arises under conditions of rapid serial visual presentation (RSVP) in normal individuals. When stimuli are presented sequentially at a rate of around ten stimuli per second and the observer has to monitor this information stream for two visual targets defined by a specific feature (e.g., color) or category (e.g., letter), the second target (T2) is often missed if it occurs within 200–600 ms of the first target (T1). This difficulty is generally attributed to a failure to consolidate T2 in visual short term memory for later report, and is hypothesized to be due to: a bottleneck in processing caused by the consolidation of T1 (Chun & Potter, 1995); a loss of attentional control over target processing caused by attending to the first target (Di Lollo, Kawahara, Ghorashi, & Enns, 2005); or active suppression of T2 in order to protect T1 from interference during encoding (e.g., Olivers & Meeter, 2008; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994). Whichever the mechanism responsible for the loss of T2, the AB phenomenon is an example of a failure of perceptual awareness somewhat akin to that seen in extinction, except under temporal, rather than spatial, stimulus competition.

Although the AB has been studied most extensively using alphanumeric characters as stimuli, the effect has also been demonstrated with words (Maki, Frigen, & Paulsen, 1997; Shapiro, Driver, Ward, & Sorensen, 1997) and pictures of objects (Dux & Harris, 2007; Evans & Treisman, 2005; Harris, Benito, & Dux, 2010; Livesey & Harris, 2011; Potter, Wyble, Pandav, & Olejarczyk, 2010). In a series of experiments using the AB paradigm, Adamo and Ferber (2009) found that if T1 was a picture of a tool (e.g., hammer) and T2 a picture of its action recipient (e.g., nail), the AB effect was reduced (i.e., T2 was correctly identified more often) as compared to when T2 was an unrelated nonaction object. A word version of the experiment failed to show any such reduction in AB, suggesting that it was not due to the semantic association between the tool and its action recipient. Finally, electroencephalography (EEG) revealed an enhanced P3 component (linked previously to working memory encoding; Luck, Vogel, & Shapiro, 1996; Vogel, Luck, & Shapiro, 1998) for T2 "hits" for action recipients relative to nonaction objects. These findings led to the suggestion that when the initial tool target is encoded into visual short-term memory (VSTM), its representation includes a motor affordance that incorporates complementing objects and their features/properties. This then facilitates the encoding of its subsequent action recipient, which matches that representation more than do the nonaction object stimuli. However, this interpretation seems premature given that Adamo and Ferber (2009) only used trials in which T1 was a tool and T2 was either a congruent action recipient or a nonaction object. Therefore it cannot be determined whether the effect, in fact, depends on the presence of the tool. It may simply be due to some inherent difference between action recipients and nonaction objects that makes action recipients less prone to an AB. Nor can their results establish unequivocally that the effect depends on the motor properties of the tool priming the encoding of subsequent action recipients; it is possible that such facilitation would occur even when the tool is presented after the action recipient, on the basis of the semantic relationship between the two objects. Nevertheless, after addressing these concerns it may be possible to use this paradigm to investigate in more detail the involvement of the motor system in the visual processing of action-object pairs.

In the present study, we first established the importance of the T1 tool in generating the tool–action recipient congruency effect in RSVP. In Experiment 1, we determined (a) whether the effect depends on the specific tool–action recipient pairing and (b) whether the effect is driven by the tool or is bidirectional. In Experiment 2 we ruled out the possibility that the better report of action recipient T2s was due to structural differences between these stimuli and the distractors. Having established that the reduction in AB is specific to the congruent tool–action recipient pairings, we then investigated its sensitivity to manipulations of the action context between the action objects. In Experiment 3 we modified the alignment of the tool with respect to its action recipient, a manipulation that directly alters the motor affordance of the tool and action recipient. This allowed us to examine whether the influence of the tool on its action recipient is sensitive to their joint action properties. Finally, in Experiment 4 we examined whether the congruency effect can be eliminated by presenting an intervening distractor tool between the target tool and action recipient. Given that distractor stimuli presented during the AB are processed to a high level (Harris & Little, 2010; Maki et al., 1997; Shapiro et al., 1997), this could disrupt the praxic program linking the tool to its action recipient. Since the tool and action recipient themselves remain physically unaltered by such a manipulation, any effect obtained is likely to be due to "online" processing of the motor properties of the objects.

General method

Participants

Participants were recruited from undergraduate psychology students at the University of Sydney in exchange for course credit, and had normal, or corrected-to-normal, vision. The experimental procedures were approved by the Human Research Ethics Committee of the University of Sydney, and all participants gave their informed consent to take part in the experiments.

Stimuli and apparatus

Stimuli consisted of line drawings of objects presented on a white background. These drawings were taken from Snodgrass and Vanderwart (1980), except where otherwise noted. Target objects were colored red, whereas distractors were colored black. Participants familiarized themselves with the pictures before starting the experiment. The stimuli subtended up to 6º of visual angle at a viewing distance of ~57 cm and were displayed on a 17-in. CRT monitor (85-Hz refresh). Stimulus presentation was controlled via MATLAB, using the Psychophysics Toolbox (version 3; Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997), running on an Apple Mac Mini computer.

Procedure

Each RSVP sequence began with the presentation of 4–6 distractor stimuli, then the first target stimulus (T1). This was followed by seven distractor stimuli interposed with a second target stimulus (T2), except in Experiment 2, in which no distractors were presented. Stimuli were presented to the upper right and lower left of fixation. Except where otherwise specified, T1 was always shown in the upper right, and T2 (if present) in the lower left. Distractors were shown in either position, randomly, except the distractor immediately following a target which was shown in the same location to act as a mask. The lag between T1 and T2 varied between one, two, four, and seven serial positions, with lag 1 being immediately subsequent to T1. We included lag 1 trials because in RSVP studies T2 stimuli presented at this temporal position are often largely unaffected by the AB—an effect known as lag 1 sparing (Potter, Chun, Banks, & Muckenhoupt, 1998). Lag 1 sparing is a robust finding that has been replicated across numerous AB experiments employing alphanumeric stimuli, although it tends to be less pronounced, and sometimes nonexistent with object stimuli (Dux & Harris, 2007; Harris, Benito, & Dux, 2010; Livesey & Harris, 2011). Lag 1 sparing is not usually found when T1 and T2 are spatially separated (Juola, Botella, & Palacios, 2004; Visser, Zuvic, Bischof, & Di Lollo, 1999), as is the case in the present experiment, but it has been shown to be restored in such situations by cuing the location of T2 (Lunau & Olivers, 2010). Thus, we were interested whether the spatial relationship inherent to the motor association between tools and action recipients might increase the likelihood of such a cueing effect, and lag 1 sparing, being observed. On single-target trials, T2 was replaced by a distractor. Each stimulus appeared for 35 ms, with an interstimulus interval of 71 ms, resulting in a stimulus onset asynchrony (SOA) of 106 ms. At the end of the stream of images, participants were asked to report any red objects they had seen; these responses were recorded by an experimenter present in the room with the participant. After they had responded, participants pressed a key to advance to the next trial when they were ready. A red cross was displayed in the centre of the screen throughout the trial to aid fixation.

Measures used

Only accuracy was recorded. T1 accuracy was not analyzed as in all experiments it was at or near ceiling performance (mean 95.6 % accuracy). In line with other studies of the AB, T2 accuracy was conditionalized on the correct report of T1 (T2 | T1). Responses were considered correct regardless of the order in which they were given. All analyses used an alpha of .05 and a Huynh–Feldt correction was applied to all analysis of variance (ANOVA) results to correct for sphericity (note that corrected *p* values, but uncorrected *df*s, are reported here). A Sidak (1967) correction was used on all post-hoc tests to compensate for multiple comparisons.

Experiment 1

Experiment 1 was a partial replication and extension of Adamo and Ferber's (2009) experiment and was designed to establish the specificity of any reduction in the magnitude of the AB for tool–action recipient target pairings. First, we determined whether the effect is actually dependent on T1 being a tool. It is possible that this effect arises simply due to low-level visual differences (e.g., size, shape) between action recipients as a group and nonaction objects. This was done by comparing trials in which T1 was a tool with trials in which T1 was a nonaction object. Second, we investigated whether any reduction in AB is specific to the particular association between a tool and its action recipient; between, for example, a hammer and a nail specifically. This was tested by including trials in which the action recipient object was incongruent with the tool (e.g., a hammer paired with a steel nut). If the effect is specific to the motor association between a tool and its action recipient, then we should observe no reduction in the AB for trials in which T1 is a nonaction object, nor for incongruent tool–action recipient pairings. Finally, we were interested in whether the effect arises as a result of the action-related properties of the tool or instead from the semantic association between the tool and the action recipient. If this effect is indeed generated by the action properties of the tool, presenting the action recipient first should not produce the same effect. On the other hand, if the effect is due to the semantic association between the tool and action recipient it should operate in either temporal sequence. To test this, we ran a second group of participants through the same experimental procedure but reversed the temporal order of T1 and T2, such that the action recipient now came first (as T1) and the tool second (as T2).

Method

Participants

A total of 38 participants were recruited for this experiment (21 female, 17 male; mean age = 22.1). All but three participants were right-handed as determined by self-report. Of the participants, 20 were assigned to the tool T1–action recipient T2 (forward) version, and 18 were assigned to the action recipient T1–tool T2 (reverse) version.

Stimuli and apparatus

The target stimuli consisted of drawings of tools, their action recipients, and a set of nonaction objects. The distractor stimuli consisted of a separate set of nonaction objects. See Table 1 for the specific objects used, and Fig. 1a for examples.

Procedure

See Fig. 1b. During the RSVP stream, stimuli were presented either to the upper right or lower left of fixation. In two-target trials, T1 was always shown in the upper right and T2 in the lower left. Distractors were shown in either position, randomly,

Table 1 Stimuli used for Experiments 1 and 2

Tool Object Targets	Action Recipient Object Targets	Nonaction Object Targets
Hammer	Nail	Handbag
Screwdriver	Screw	Window frame
Saw	Plank†	Glass (cup)
Scissors	Paper†	Toaster
Axe	Log†	Bed
Wrench	(Steel) Nut	Clock
Key	Lock	Chair
Distractors		
Book	Record player	
Couch	Shirt	
Glasses	Shoe	
Hat	Suitcase	
Lamp	TV	
Letterbox†	Vase	
Phone	Watch	

† This drawing was created for the experiment, rather than taken from Snodgrass and Vanderwart (1980).

except for the distractor immediately following a target, which was shown in the same location to act as a mask. One sixth of trials were designated single-target trials, in which only a single target (a tool, an action recipient, or a nonaction recipient) in the T1 position was shown. The particular T1–T2 combinations were determined by creating seven object groupings. Each group was based on one of the action objects. Note that the "action object" refers to a tool in the forward version, and an action recipient in the reverse version (i.e., whichever was T1). Each grouping included the action object's congruent action associate (e.g., "nail" for a group based on "hammer," or "hammer" for a group based on "nail"), an incongruent action associate (e.g., "screw" for a group based on "hammer" or "screwdriver" for a group based on "nail"), and two nonaction objects. The action object and a nonaction object were used as T1 stimuli. For each of these, the congruent action associate, the incongruent action associate, and a nonaction object were used as T2. Note that in the case of nonaction T1 trials, the congruent and incongruent action associates are referred to as Recipient 1 and Recipient 2 in the forward version, or Tool 1 and Tool 2 in the reverse version, since the congruency had no meaning in those situations. The incongruent action associates were determined randomly for each participant, with the proviso that they could not occur together in any other grouping. This then created six conditions in each of the forward and reverse versions of the experiment. For the forward version, these were tool (T1)–congruent recipient (T2), tool–incongruent recipient, tool–nonaction object, nonaction object–Recipient 1, nonaction object–Recipient 2, and nonaction object–nonaction object. For the reverse version, these were recipient (T1)–congruent tool (T2), recipient–incongruent tool, recipient–nonaction object, nonaction object–Tool 1, nonaction object–Tool 2, and nonaction object–nonaction object.

The experiment was run in two blocks. In each block, every condition was presented seven times at each lag (i.e., once per specific object grouping). Furthermore, each of the target objects was presented twice in single-target trials. This resulted in a total of 210 trials per block. Given the self-pacing within the experiment, the duration of the experiment varied from participant to participant, but on average took approximately 45 min.

Results

T2 | T1 accuracy

T2 accuracy data, conditionalized on T1 (T2 | T1) were entered into a mixed-measures ANOVA using T1 category (two levels: action object and nonaction object), T2 category (three levels: congruent action associate, incongruent action associate, and nonaction object), and T2 lag (four levels: 1, 2, 4, and 7) as within-subjects factors and Version (two levels:

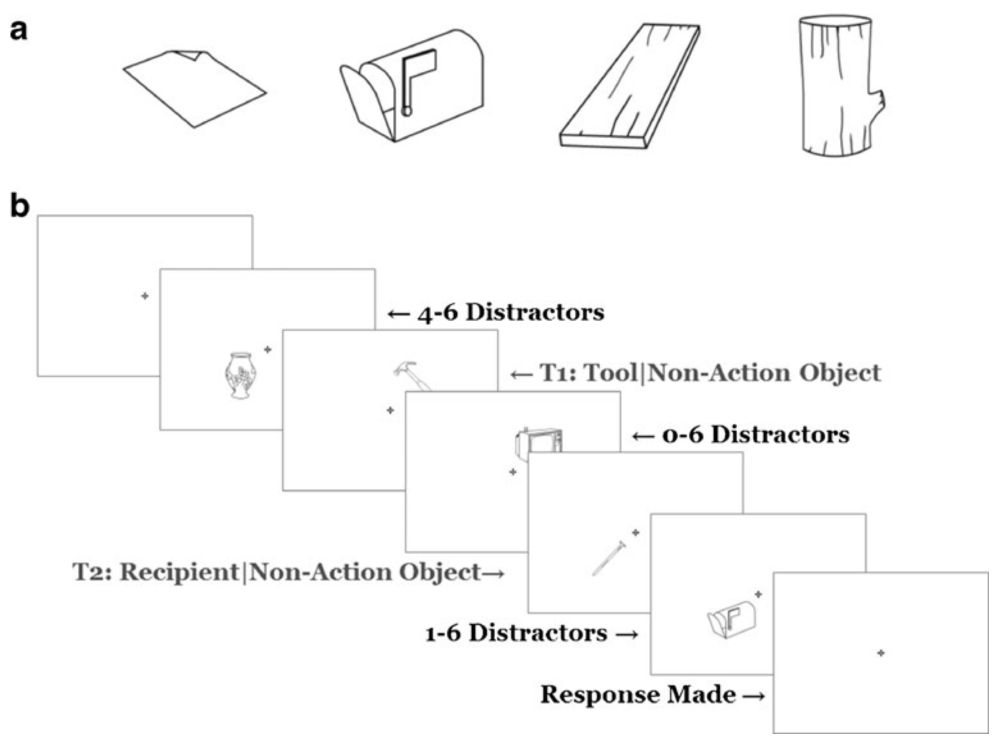

Fig. 1 Examples of stimuli and trial sequence used in Experiment 1. **a** Stimuli generated specifically for this experiment (i.e., not taken from Snodgrass & Vanderwart, 1980): paper, mailbox, plank, and log. Refer to Table 1 for all of the stimuli. **b** The trial sequence. T1 was either a tool or a nonaction object, and T2 was either an action recipient object (congruent or incongruent with the tool T1) or a nonaction object. The distractors were all nonaction objects. In the actual experiment, T1 and T2 were red, and the distractors were black

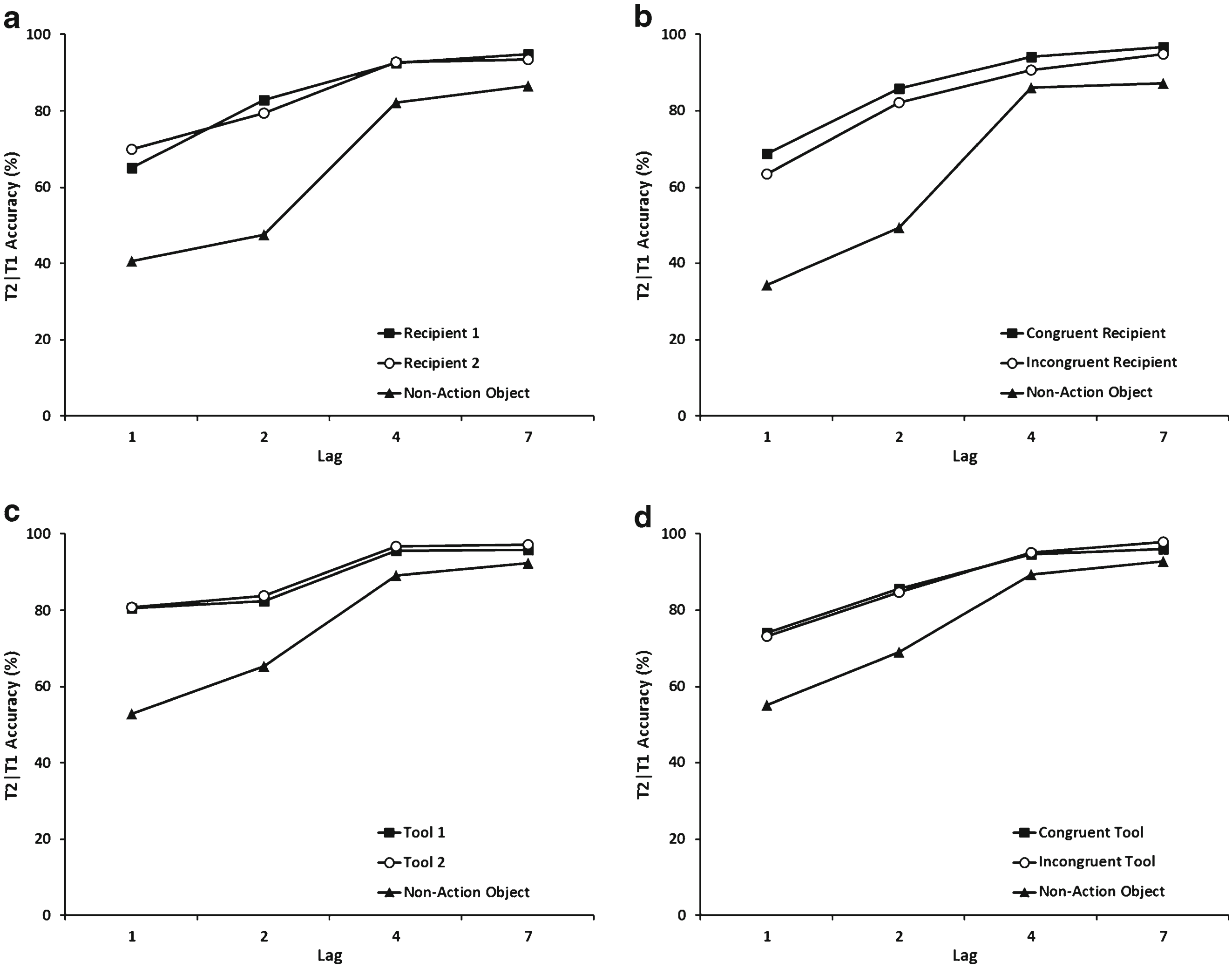

Fig. 2 Conditional T2 (T2 | T1) accuracy for nonaction object (**a**) and tool (**b**) T1 trials across each T2 object category in the forward version, and for nonaction object (**c**) and action recipient (**d**) T1 trials across each T2 object category in the reverse version of Experiment 1

forward and reverse) as a between-groups factor. These data are summarized in Fig. 2.

We found significant main effects of T2 category [$F(2, 70) = 125.75$, $p < .001$, $\eta_p^2 = .782$], with nonaction objects being reported less accurately than all types of action objects, and T2 lag [$F(3, 105) = 80.73$, $p < .001$, $\eta_p^2 = .698$], indicating the presence of an AB in all conditions (see Fig. 2). Interactions also emerged between T2 category and version [$F(2, 70) = 6.95$, $p = .007$, $\eta_p^2 = .166$], T2 category and T2 lag [$F(6, 210) = 48.51$, $p < .001$, $\eta_p^2 = .581$], T1 category and T2 lag [$F(3, 105) = 4.28$, $p = .007$, $\eta_p^2 = .109$], T2 category, T2 lag, and version [$F(6, 210) = 5.40$, $p = .001$, $\eta_p^2 = .134$], and T1 category, T2 category, and version [$F(2, 70) = 3.60$, $p = .035$, $\eta_p^2 = .092$]. No other effects or interactions reached significance ($p \geq .128$).

The presence of higher-level interactions indicates that the report of T2 was modulated both by the nature of the target stimuli (action object or nonaction object) and by the order in which stimuli were presented. A breakdown of the three-way interaction between T1 category, T2 category, and version showed that, across all conditions, nonaction objects were reported less accurately than action objects ($p \leq .001$; see Fig. 2). On the other hand, successful reporting of action object targets was modulated by the action status of T1. When T1 was a nonaction object, we observed no difference between the different T2 action objects in either version ($p \geq .785$). However, when T1 was an action object in the forward version (i.e., a tool), congruent action recipients were reported more accurately than incongruent action recipients ($p < .001$). No such difference was observed in the reverse version—that is, when T1 was an action recipient ($p = .999$). In other words, a tool T1 seems to offer some protection from the AB to its congruent action recipient, but an action recipient T1 does not offer the same boost to its corresponding tool.

Investigating the interaction between T2 category, T2 lag, and version, we found that, in the forward version, the difference in accuracy between action and nonaction objects was significant, or at least approached significance, at all lags ($p \leq .070$). In contrast, in the reverse version the improved accuracy for action objects was only present at lags 1, 2, and 4 ($p \leq .058$); at lag 7, there were no significant differences in accuracy between action and nonaction objects ($p \geq .319$). In addition, we found no evidence of lag-1 sparing in any of the conditions. For the forward version, overall, T2 accuracy increased at each lag up to lag 4 ($p \leq .035$), with no further change to lag 7 ($p \geq .129$). In the reverse version, T2 accuracy was largely similar, except that accuracy for tools did not significantly improve from lag 1 to lag 2 ($p \geq .271$).

Finally, the interaction between T1 category and T2 lag was found to be difficult to interpret in a straightforward manner, and therefore will not be discussed further.

Single-target accuracy

Single-target trial accuracy was analyzed using a separate mixed-measures ANOVA with Category (three levels: tool, action recipient, nonaction object) as a within-subjects factor and Version (two levels: forward and reverse) as a between-groups factor. A significant difference was apparent between the object categories on single-target trials [$F(2, 72) = 10.435$, $p < .001$, $\eta_p^2 = .225$]. Tools (99 %) and action recipients (98 %) had slightly higher accuracy on single-target trials than did nonaction objects (96 %; $p \leq .020$), but they did not differ from each other ($p = .382$). No effect of version was observed.

Discussion

In the present experiment, we found a slight, but significant, reduction in the AB for congruent tool–action recipient pairings (e.g., hammer–nail) relative to incongruent pairings (e.g., hammer-lock). This provides support for the specific association between a tool and its action recipient protecting that recipient from the AB. We also found that reversing the temporal order of the pairings, such that the action recipient was presented before the tool, resulted in no significant accuracy benefit for congruent pairings over incongruent ones. This supports the idea that the effect depends on the tool being presented first, although it still does not fully substantiate Adamo and Ferber's (2009) postulate that the tool creates a motor affordance in VSTM that promotes the encoding of a subsequent, congruent action recipient.

One potential confound was that during the familiarization process participants were made explicitly aware of the specific tool–action recipient associations that were used. This may have biased the participants to focus on identifying these specific associations as they were performing the experiment. To address this, we reran the forward version of the experiment on 14 new participants, this time without explicit instruction of the tool–action recipient associations. We replicated the original finding of a significant increase in accuracy for congruent tool–action recipient pairings relative to incongruent pairings, demonstrating that it was not due to the instructions.

In addition to the reduced AB for congruent as compared to incongruent action recipients, we also found that T2 action recipient objects overall experienced a much reduced AB as compared to nonaction objects. This effect was strongest at the earliest lags (1 and 2), and was observed regardless of the identity of the T1 target stimulus (tool or nonaction object). In a recent study, Tibboel, De Houwer, Spruyt, and Crombez (2011) showed that T2 stimuli that formed a coherent semantic group, in their case music-related words, showed less AB than unrelated, neutral stimuli. This could potentially explain the results we obtained with tool T2s. Although it seems unlikely that the action recipient stimuli can be grouped together to form a coherent semantic category in the same way, participants may have constructed some kind of "target template" incorporating action objects (tools and action recipients). The congruency effects may then arise due to interactions between the template and semantic associations between the objects in question—although it is not clear why this would only apply in one direction (the forward version) and not both. Alternatively, the effect might also be due to differences in the physical characteristics of the tools and action recipients and nonaction stimuli. The AB has been found to be reduced by featural salience of the T2 stimulus relative to other stimuli in the stream (e.g., Chua, 2005; Shih & Reeves, 2007). In our experiment, tools and action recipients tended to be smaller and have a different shape than nonaction objects (i.e., more elongated and rectangular). Given that the distractors used in the present experiment were all nonaction objects, the tool and action recipient T2 stimuli may have been less effectively masked by the distractors than the nonaction T2 stimuli and thus easier to process. We investigated this in Experiment 2 by removing any influence from distractor stimuli.

Experiment 2

Experiment 2 employed a "skeletal" RSVP sequence. This design, which still induces an attentional blink, uses no distractor stimuli; only two target stimuli, and accompanying masks, are presented (Ward, Duncan, & Shapiro, 1997). Variable SOAs are then used to produce "lag." This design allows us to examine whether the differences observed in Experiment 1 for tools and action recipients, as compared to nonaction objects, were due to the similarity (or lack thereof) of distractor stimuli to the targets, given that all distractors used in Experiment 1 (and eliminated here) were nonaction objects. If so, we would expect no difference in the size of the attentional blink between nonaction object targets and incongruent action recipient targets (the improved accuracy for congruent action recipient targets should remain unaffected).

Method

Participants

A group of 24 participants took part in this experiment (21 female, three male; Mean age = 20.3). All of the participants were right-handed, as determined by self-report.

Stimuli and apparatus

Target stimuli were identical to Experiment 1, except colored black. Distractor stimuli were not used. Six mask images were created for the experiment, using random black lines and shapes. The mask images subtended the same visual angle as the target stimuli.

Procedure

The procedure was largely identical to the forward version of Experiment 1. The timing of the sequence was kept identical by simply replacing the distractors with a blank screen of the same duration. The SOAs thus used were 106 ms (equivalent to lag 1), 212 ms (lag 2), 424 ms (lag 4), and 742 ms (lag 7). Masks were shown after each target image, except after T1 on the 106-ms SOA trials. For single-target trials a pair of mask images was shown at one of the four SOA positions used in two-target trials. This was done in order to equate the trial experience between single- and two-target trials.

Results

T2 | T1 accuracy

The statistical analysis was handled similarly to that of Experiment 1, with SOA replacing lag as a factor. On the basis of our experimental hypothesis and the results of Experiment 1, planned pairwise comparisons were used to investigate the T1 Category × T2 Category interaction in more detail.

These comparisons showed that congruent tool–action recipient pairings had a reduced AB, relative to incongruent pairings (p = .030) and to nonaction objects (p = .045; see Fig. 3b). Importantly, this time we saw no difference between incongruent tool–action recipient and tool–nonaction object pairings (p > .999). Furthermore, when T1 was a nonaction object, no significant differences emerged between any of the T2 categories ($p \geq .423$).

Single-target accuracy

Single-target trial data were analyzed in a one-way within-subjects ANOVA with category (three levels: tool, action recipient, nonaction object) as the single factor, which revealed no significant differences in accuracy amongst the three target object types [action recipients = 97 %, nonaction = 98 %, tools = 97 %; $F(2, 46) < 1$].

Discussion

In Experiment 1, we found a reduced AB for congruent tool–action recipient object pairs, but only when the tool preceded the action recipient in the temporal sequence. However, we also observed a reduced AB for action objects in general, as compared to nonaction objects. Thus we could not rule out the possibility that the congruency effect arose from an interaction between a putative “target template,” created to isolate action object targets against the nonaction object distractors, and purely semantic associations between the tool–action recipient pairs, rather than from action links between tools and their action recipients. In Experiment 2, we attempted to address this by removing the distractor stimuli completely. This should have

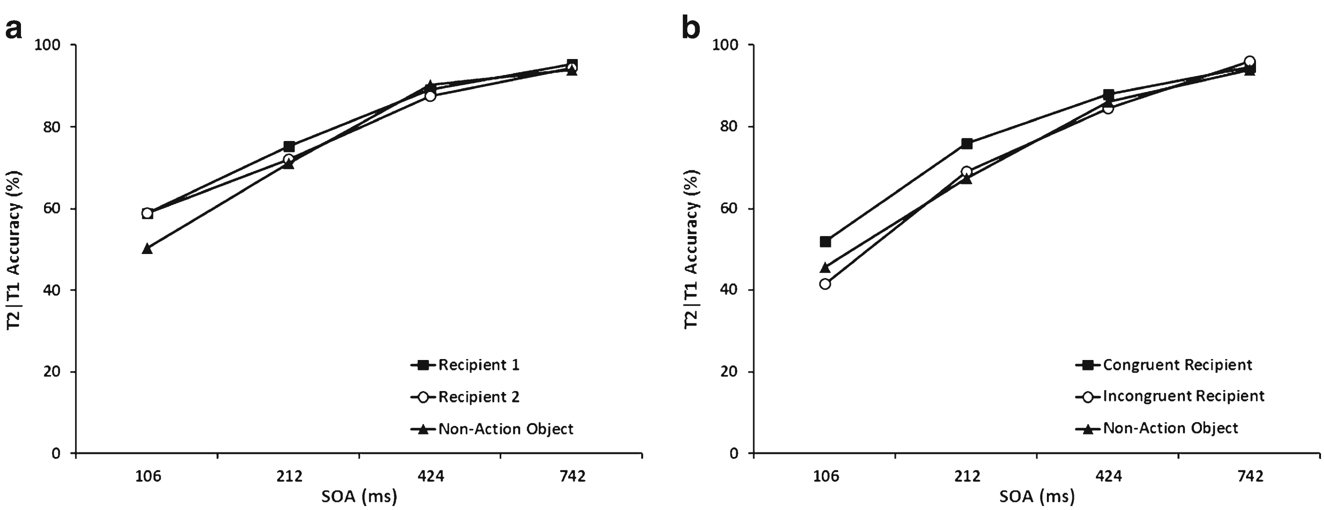

Fig. 3 Conditional T2 (T2 | T1) accuracy for nonaction object (**a**) and tool (**b**) T1 trials across each T2 object category in Experiment 2. The stimulus onset asynchronies (SOAs) of 106, 212, 424, and 742 ms correspond to the lags of 1, 2, 4, and 7 (respectively) used in the other experiments

eliminated the need to create any categorical templates by which targets can be selected from distractors, as well as removing any possibility that the reduced AB was due to structural image differences between action object targets and nonaction object distractors leading to less effective visual masking. Under these conditions, there was no longer an overall difference in the size of the AB suffered by action recipients and nonaction objects. However, the improved T2 accuracy for congruent tool–action recipient pairs as compared to incongruent pairs (and nonaction objects) remained.

It is possible that the congruency effect found in Experiments 1 and 2 is due to guessing. Specifically, when presented with a tool T1, participants may be biased toward guessing its action recipient when they are unsure about the identity of T2. We examined the number of such “false alarms”: identifying a T2 incongruent action recipient or nonaction object as a congruent action recipient on tool T1 trials. We then took the number of substitution errors (an incorrect T2 response involving a different object) and calculated the expected number of false alarms assuming no such effect. We found no significant difference between the total number of false alarms observed (18) and what we would expect by chance alone (14.9). Therefore, the observed effect is unlikely to be due to this kind of guessing strategy. We can therefore be more confident that the facilitation is specific to the tool–action recipient pairings. Together with the unidirectional tool-to-recipient effect seen in Experiment 1, this provides stronger evidence for the notion that identifying a tool includes encoding its action affordances in VSTM, which in turn facilitates the encoding of action recipients that match those action affordances. However, the evidence for this motor hypothesis is still largely circumstantial. In the following two experiments, we attempt to test this more directly, by manipulating the specific motor congruence between a tool and its action recipient through an object rotation (Exp. 3) and by introducing potential interference from a distractor tool with different motor affordances (Exp. 4).

Experiment 3

The previous set of experiments established that the AB motor congruency effect is attributable to the specific relationship between the tool and its action recipient. However, these findings do not unequivocally establish the motoric aspect of the effect. If the reduced AB is indeed due to the motor affordance generated by the tool then it should be sensitive to manipulations of the tool that affect its readiness for motor interactions with an action recipient. In Experiment 3, we examined whether the facilitation observed for congruent tool–action recipient pairings is reduced, or even eliminated, when the objects are no longer presented in an orientation that suggests they are interacting with each other.

Method

Participants

A group of 25 people participated in Experiment 3 (17 female, eight male; Mean age = 18.4). All but two of the participants were right-handed, as determined by self-report.

Stimuli and apparatus

For Experiment 3, we used only the tool and action recipient stimuli from Experiment 1. We also included versions of each of the tool stimuli that were rotated such that, instead of being positioned as if to act on the subsequent action recipient in the bottom left, the functional part of the tool pointed directly away from the action recipient, toward the upper right.

Procedure

The procedure was altered from that of Experiment 1 by removing both the nonaction T1 and nonaction T2 categories. Instead, we used aligned (oriented as if interacting with the subsequent action recipient) and misaligned (oriented away from the subsequent action recipient) tools as T1 categories, each occurring with either congruent or incongruent action recipient T2 stimuli. Also, for single-target trials only tool stimuli, aligned and misaligned, were shown. Finally, in order to try to get performance away from ceiling, we reduced the inter-stimulus interval during the RSVP stream from 71 to 47 ms, resulting in an SOA of 82 ms.

Results

T2 | T1 accuracy

T2 | T1 accuracy data were entered into a repeated measures ANOVA, using T1 Category (two levels: aligned vs. misaligned tools), T2 Category (two levels: congruent vs. incongruent action recipient), and T2 Lag (four levels: 1, 2, 4, and 7) as factors. We observed significant main effects of T2 category [$F(1, 24) = 62.67$, $p < .001$, $\eta_p^2 = .723$], with overall better performance for congruent than for incongruent pairs, and of T2 lag [$F(3, 72) = 36.68$, $p < .001$, $\eta_p^2 = .603$], consistent with an AB. We also found significant interactions between T2 category and T2 lag [$F(3, 72) = 10.57$, $p < .001$, $\eta_p^2 = .306$] and T1 category, T2 category, and T2 lag [$F(3, 72) = 2.86$, $p = .048$, $\eta_p^2 = .106$].

Pairwise comparisons of the three-way interaction revealed that for aligned tools, accuracy for congruent recipients was significantly higher than that for incongruent recipients at lags 1 and 2 ($p < .001$), but did not differ at lag 4 or 7 ($p \geq .560$; see Fig. 4a). For misaligned tool T1 trials, accuracy was significantly higher for congruent than for incongruent recipients at

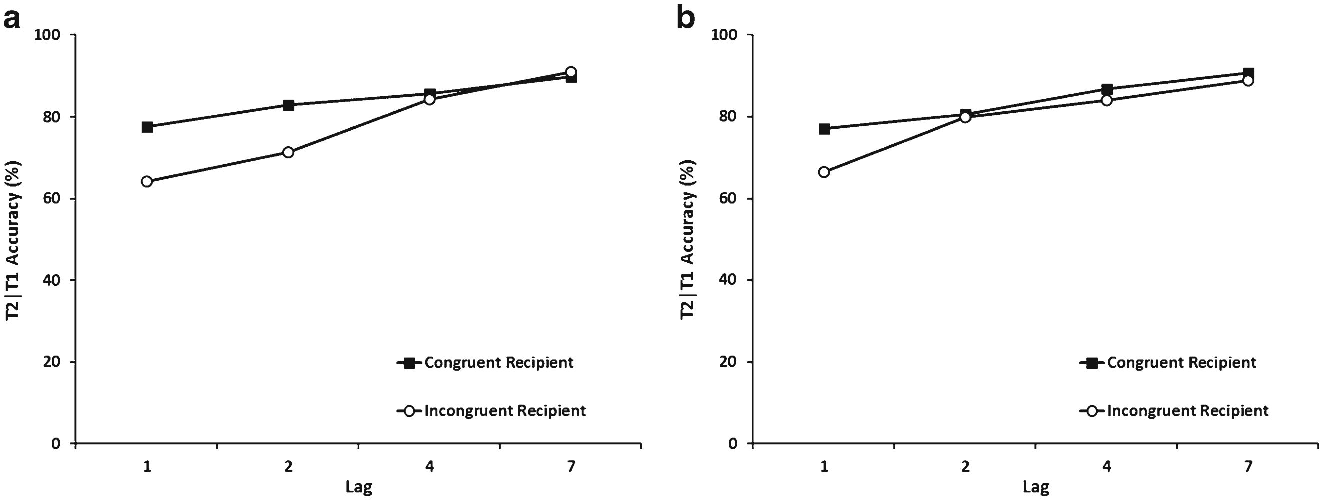

Fig. 4 Conditional T2 (T2 | T1) accuracy for aligned tool (**a**) and misaligned tool (**b**) T1 trials across each T2 object category in Experiment 3

lag 1 (p < .001), but not at any other lag ($p \geq$ .142; see Fig. 4b). This suggests that the AB, which is usually maximal at lag 2, was reduced for congruent as compared to incongruent pairs only when the tool was correctly aligned for interacting with the action recipient.

Single-target accuracy

Single-target trial accuracy was analyzed with a paired-samples t test comparing aligned and misaligned tool targets, which revealed no significant difference in accuracy between aligned (96 %) and misaligned tools (96 %) [$t(24)$ = 0.01, p = .992].

Discussion

In this experiment, we found that rotating a tool, such that it is no longer positioned to "act" on the subsequent action recipient, had different effects on the size of the AB for congruent and incongruent action recipients. This was in spite of the fact that this manipulation made no difference to the participants' ability to accurately identify the tool T1 target object, as demonstrated by the similar accuracy on single-target trials. These findings provide stronger evidence that the effect is due to the action affordance of the tool, rather than the semantic relationship between the tool and action recipient, which should not change when the tool is rotated. Indeed, Yoon and Humphreys (2007) have shown that semantic priming with pictures of tools occurs irrespective of changes in the positioning of the tool handle toward or away from the observer. However, Yoon and Humphreys (2007) did find that orientation changes do affect action decisions about the tools. Perturbing motoric properties of visually presented tools has been demonstrated to affect behavioral responses even in the absence of overt motor responses to the tools themselves (e.g., Helbig, Graf, & Kiefer, 2006; Valyear & Culham, 2010; Yoon & Humphreys, 2005). Furthermore, neuroimaging studies of such manipulations have found activity in fronto-parietal motor areas when observers simply looked at tools (e.g., Chao & Martin, 2000; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003), suggesting a key role for the motor system in the visual processing of tools and other manipulable objects. Such activation is also seen when evaluating the spatial alignment or functional compatibility of tools and recipients (Bach, Peelen, & Tipper, 2010). Given that the reduction in AB was sensitive to the alignment of the tool relative to its action recipient, this supports the idea that the better encoding of T2 action recipients is related to the contextual processing of the motor properties of the tool.

Interestingly, the difference in the congruency effect between aligned and misaligned tool trials was observed only at lag 2, whereas at lag 1 a tool–action recipient congruency effect was obtained for both aligned and misaligned tools. One possible reason for this might be that the misaligned tools provide a weaker activation of contextually appropriate motor properties (Petit, Pegna, Harris, & Michel, 2006). By rotating the tools, they become positioned in a way that requires a more awkward functional grasp from the right hand, thus affecting the synergy of the response from the motor system with the following recipient. But although the reduced AB for misaligned tools is certainly more transient than for aligned tools, its magnitude at lag 1 does not differ from that observed with aligned tools (misaligned, 12 %; aligned, 13 %). This seems incompatible with the idea of "weaker" activation. An alternative explanation is that the results of this experiment are due to differential shifts of attention elicited by aligned and misaligned tools. It has been shown that tools can shift spatial attention in the direction of their effective action (Roberts & Humphreys, 2011). Thus, aligned tools may shift attention toward the spatial location at which the T2 action recipients will subsequently appear, whereas misaligned tools shift attention away. The increased accuracy for congruent action recipients could then be purely attributed to the semantic association between the target objects rather than having anything to do with their action congruency. The reduced AB at lag 1 for congruent action recipients following misaligned tools might be explained by a delay in the shifting of attention. Jefferies and Di Lollo (2009) recently showed, using an RSVP paradigm with two stimulus streams like ours, that attention can take up to 100 ms from presentation of the T1 stimulus to contract from monitoring both streams to focus on the stream in which the first target is located. Therefore the 82-ms SOA used in the present experiment would mean that action recipients at lag 1 could still benefit from any semantic association with a preceding, misaligned tool before attention is shifted away. Indeed, it may be possible to extend this explanation regarding shifts of attention to the results in our previous experiments as well. The reason we did not observe any early priming effects in the reverse condition of Experiment 1 (i.e., from action recipients to tools) is because action recipients do not generate these same shifts of attention as do tools, and thus would not produce any improvement in accuracy for a subsequent tool at these early lags. Any such priming that might be observed at later lags for congruent tool–action recipient pairing, regardless of temporal order or alignment, could be masked by ceiling effects in accuracy. However, if this were the case we would expect that T2 accuracy following a misaligned tool would be reduced at lag 2 (i.e., 164 ms after the shift of attention has taken place) relative to those following aligned tools. Instead, we found no significant decrease in T2 accuracy for action recipients for trials with misaligned tools at lag 2 (80.2 %) relative to aligned tools (77.1 %; p = .136). Therefore, it is unlikely that these results can be explained simply through shifting of spatial attention coupled with semantic priming.

As a final alternative, it is possible that different processes mediate the congruency effect at lag 1 and at lag 2. A number of theoretical accounts of the AB postulate that when targets occur consecutively in an RSVP stream (i.e., at lag 1), they are incorporated in the same attentional episode and, thus, may enter VSTM together (e.g., Di Lollo et al., 2005; Potter et al., 1998; Wyble, Bowman, & Nieuwenstein, 2009). In contrast, targets separated by at least one intervening distractor (i.e., lag 2 and beyond) are processed in distinct attentional episodes. Thus, it may be the case that in the lag 2 condition, a correctly aligned tool T1 activates the relevant motor features, which then provide an attentional boost and facilitate the subsequent encoding of a congruent action recipient T2, as compared to an incongruent T2. A misaligned tool that is not positioned to interact with the subsequent action recipient, may not generate the same attentional boost, resulting in similar levels of encoding for congruent and incongruent action recipients. At lag 1, on the other hand, if T1 and T2 enter VSTM together, the motor affordance of the tool may not confer any attentional advantage, resulting in no difference between aligned and misaligned tools. In this case, the congruency effect may be due to the semantic relationship between the tool and its action recipient, which is the same for aligned and misaligned tools. Although this is admittedly a speculative account, some evidence lends plausibility to such an idea.

Current models of tool use posit a distributed representation incorporating two systems (Boronat et al., 2005; Buxbaum, 2001; Buxbaum & Saffran, 2002). The first is a production system responsible for the sensorimotor transformations for action. The second, the praxic semantic system, contains knowledge about objects and their use. The praxic semantic system is further divided into: (1) conceptual knowledge about tool *function*; and (2) action semantics related to tool *manipulation*. Therefore, on presentation of a T1 tool an initial representation of the tool may be activated that provides access to functional knowledge about what the tool is used for (i.e., a hammer is used on a nail). This representation does not depend on knowing how the tool should be oriented to act on the recipient, and may be what accounts for the congruency effect at lag 1 for both aligned and misaligned tools. Conversely, information about how the tool must be manipulated in order to act on the recipient is context-dependent, as it requires information about the actual positioning of the tool and its recipient. Therefore, delayed access to this information may account for the difference in the tool–action recipient congruency effect at lag 2.

Although the results from Experiment 3 are consistent with the involvement of the motor system in the visual processing of tools and action recipients, the misalignment of the tool also affects our usual visual experience with such objects (even though we did not observe any significant difference between aligned and misaligned tools in single target trials) and, as discussed above, could produce differences in attentional shifts to these stimuli. In the next experiment we test this further by attempting to interfere with the motor affordance generated by the tool without altering the appearance and positioning of the tool and action recipient target objects themselves.

Experiment 4

In Experiment 4, we examined whether interposing a second tool as a distractor between T1 and T2 interferes with the motor manipulation representation of a tool T1 and removes the benefit in detecting a congruent action recipient T2 that was observed in the previous experiments. Distractor stimuli occurring during the AB have been shown to be processed to a high (conceptual) level, producing semantic priming of T2 stimuli (Harris & Little, 2010; Maki et al., 1997; Shapiro et al., 1997). Given this, tools presented as distractors may be processed to the level of their functional and manipulation-based representations. This should interfere with those representations generated by the preceding target tool, and thereby eliminate the reporting benefit for congruent action recipients at T2.

Method

Participants

A group of 18 people participated in Experiment 4 (eight female, ten male; Mean age = 19.4). All but two of the participants were right-handed, as determined by self-report.

Stimuli and apparatus

Given the limited range of suitable objects from Snodgrass and Vanderwart (1980), pictures from a photo database (Hemera Inc., Canada) were used instead. Fourteen tool stimuli were selected, seven to serve as T1 and seven as the distractor following T1 (T1 + 1 position). Tool T1 + 1 distractors were selected to have grips and actions dissimilar from those of the target tools with which they were paired (McNair & Harris, 2012). Also, seven action recipients were congruent with the T1 tools, and 14 nonaction stimuli were used as nonaction T2s and T1 + 1 distractors and were paired with tools randomly. See Table 2 for a full list of the groups of critical stimuli used. Finally, a separate group of 13 nonaction distractors appeared at other positions in the RSVP stream. All pictures were converted to grayscale, and then target stimuli were adjusted to a white–red gradient (i.e., grayscale black became pure red).

Procedure

The procedure was very similar to the forward version of Experiment 1, except no nonaction T1 trials were presented; all of the T1s were tools. T2 could be a congruent recipient, an incongruent recipient (created by randomly shuffling the recipients to no longer match their corresponding tools), or a nonaction object. Within this design, the object distractor at the T1 + 1 position was either another tool or a nonaction object. T2 occurred at lags 2, 4, and 7. On single-target trials, only tool T1s were shown with either their paired tool or nonaction T1 + 1 distractor. We created 14 trials per condition at each lag, making a total of 252 trials, and the interstimulus interval was 67 ms (resulting in an SOA of 100 ms).

Table 2 Stimuli used for Experiment 4

Tool (T1)	Recipient (T2)	Nonaction Target (T2)	Tool T1 + 1 Distractor	Nonaction T1 + 1 Distractor
Hammer	Nail	Book	Pen	Chair
Screwdriver	Screw	Watch	Nutcracker	Trousers
Saw	Plank	Barrel	Pliers	Glasses
Scissors	Paper	Toaster	Corkscrew	Table
Axe	Log	Bed	Peg	Lamp
Wrench	(Steel) Nut	Phone	Stamp	Bath
Key	Lock	Clock	Spray bottle	Vase

Results

T2 | T1 accuracy

T2 | T1 accuracy data were analyzed using a repeated measures ANOVA with T1 + 1 distractor (two levels: tool vs. nonaction object), T2 category (three levels: congruent action recipient, incongruent action recipient, and nonaction object), and T2 lag (three levels: 2, 4, and 7) as factors.

This showed a significant main effect of T2 lag [$F(2, 34) = 26.93$, $p < .001$, $\eta_p^2 = .613$], consistent with an AB, and a significant interaction between T1 + 1 distractor, T2 category, and T2 lag [$F(4, 68) = 3.22$, $p = .018$, $\eta_p^2 = .159$]. No other main effects or interactions reached significance.

To break down the three-way interaction, we examined tool and nonaction T1 + 1 distractor trials separately and found significantly better performance for congruent than for incongruent recipients at lag 2 ($p = .006$) when T1 + 1 was a nonaction object (see Fig. 5a). This replicates the congruency effect seen in Experiment 1. We also observed a tendency for congruent recipients to be reported more accurately than nonaction T2s, although this difference was not significant ($p = .228$). However, when the T1 + 1 distractor was a tool, we found no significant difference between congruent and incongruent action recipients at lag 2 ($p = .530$; see Fig. 5b). In other words, the tool T1 + 1 distractor disrupted the facilitation in naming action recipients congruent with T1. For both T1 + 1 distractor types, no other differences approached significance ($p \geq .494$).

We also compared performance on tool and nonaction T1 + 1 distractor trials for each T2 category separately. Congruent action recipients had significantly lower accuracy at lag 2 when T1 + 1 was a tool than when it was a nonaction object ($p = .006$). No difference was found at lags 4 ($p = .922$) or 7 ($p = .643$). For incongruent action recipients, no significant differences in accuracy were found at any lag ($p\text{s} \geq .101$). Finally, no differences were observed at any lag for nonaction T2 stimuli across different T1 + 1 distractor types ($p\text{s} \geq .695$). Again, this indicates that the alleviation of the AB for congruent action recipients only occurs when there is no interference from a different tool distractor.

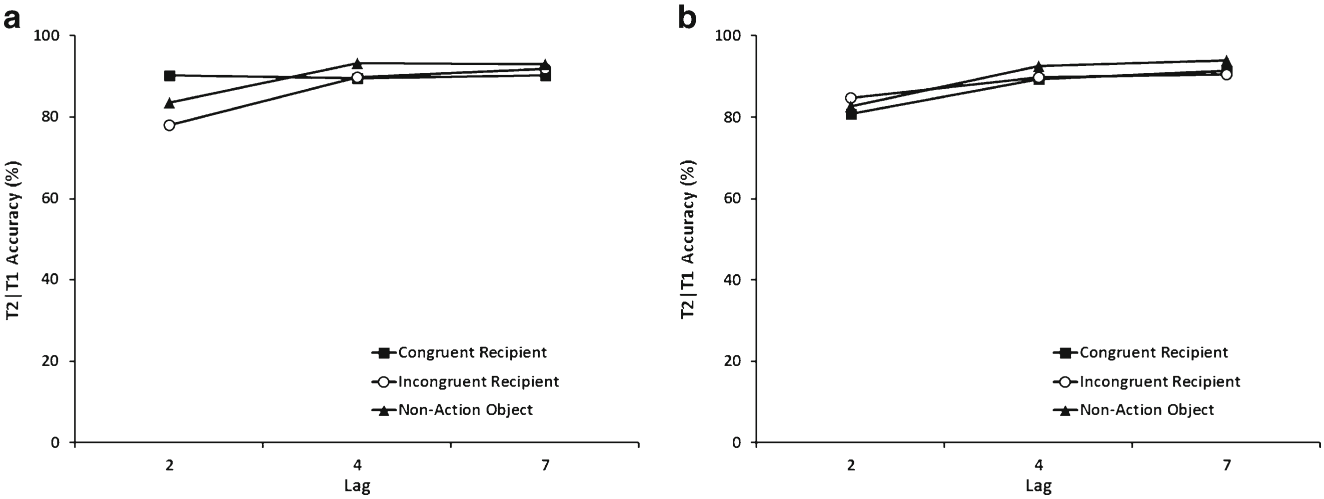

Fig. 5 Conditional T2 (T2 | T1) accuracy for nonaction object (**a**) and tool (**b**) lag-1 distractors in the T1 + 1 distractor trials across each T2 object category in Experiment 4

Single-target accuracy

Single-target trial accuracy was analyzed with a paired-samples t test comparing trials in which T1 + 1 was a tool versus a nonaction object. We observed no significant difference in accuracy on single-target trials between tools that were followed by a tool distractor (95 %) or a nonaction distractor (97 %) [$t(17) = 1.32$, $p = .205$].

Discussion

This experiment demonstrates that another tool presented immediately after a tool T1 eliminated any benefit for T2 action recipients that were congruent with the T1 tool. For nonaction T1 + 1 distractors we found a similar pattern of results to that observed in previous experiments: Congruent action recipients suffered less of an AB than incongruent action recipients. When T1 + 1 was a tool, however, this difference was not present. In addition, congruent action recipients had lower accuracy in tool T1 + 1 trials than in nonaction T1 + 1 trials.

Given that in this experiment we found no changes to the action stimuli themselves that could account for attentional shifts or changes in the perceptual familiarity of the stimulus configurations, these results provide strong support for the idea that action recipient T2 objects are less susceptible to an AB due to their congruency with the motoric representation of a tool T1. It appears that the tool distractor presented in the T1 + 1 position activates a motor affordance that conflicts with that of the T1 tool. Some direct evidence of this interference comes from the slight, albeit nonsignificant, trend for lower recall on single-target trials for tool T1 + 1 trials. Furthermore, although we did not investigate T1 accuracy in most experiments, as accuracy was very close to ceiling, here we conducted a post-hoc analysis and found that T1 performance was significantly impaired on tool T1 + 1 trials (92 %) relative to nonaction T1 + 1 (96 %; $p = .009$). The present findings parallel previous demonstrations that the motor affordance of a visually presented manipulable object can disrupt a motor response (e.g., Tucker & Ellis, 2001) and that this affordance-based compatibility effect occurs even though the response decision is independent of the actual motor properties of the object and even when the affordance-inducing stimulus is presented under very rapid presentation times and backward-masked (Tucker & Ellis, 2004). In a similar vein, some recent studies from our lab have shown that manipulable objects interfere with visual recognition of other manipulable objects that have conflicting motor affordances, but facilitate the recognition of objects with similar motor affordances (Harris, Murray, Hayward, O'Callaghan, & Andrews, 2012; McNair & Harris, 2012).

It might be argued that an alternative explanation for this reduction in accuracy for T1 stimuli is that the T1 + 1 tool attracts more attention than a nonaction object at the same position—perhaps by sharing similar featural or semantic representations as the T1 tool. However, attentional capture by a distractor generally has a deleterious effect on the subsequent T2 stimulus (Ariga & Yokosawa, 2008; Folk, Leber, & Egeth, 2002; Maki & Mebane, 2006). Yet, in our study, recall of nonaction T2 objects was no worse when T1 + 1 was a tool than when it was a nonaction object, which argues against a general attentional capture by a tool distractor.

General discussion

In a series of experiments, we investigated whether congruent tool–action recipient object pairings are less susceptible to an AB (i.e., have privileged access to perceptual awareness) and whether this is related to contextual processing of the action relationship between the objects. First, we established that AB was significantly less pronounced for congruent tool–action recipient pairings than for incongruent ones (Exp. 1: forward version). Incongruent tool–action recipient pairings did not produce the same level of facilitation. Additionally, although action objects as a whole showed a reduced AB relative to nonaction objects at the T2 position (Exp. 1), this was found to be most likely due to the similarity, or lack thereof, between the physical characteristics of the T2 stimuli and the nonaction object distractors (Exp. 2). Together, these findings suggest that the specific relationship linking the congruent tool–recipient pairs does play a role in recognition. Second, we found that this congruency effect requires the tool to be presented before the action recipient; presenting the action recipient first did not reduce the AB experienced for its associated tool (Exp. 1: reverse version). Third, we also found that the alleviation of the AB for action recipients was sensitive to whether or not the tool was positioned to act on the action recipient (Exp. 3). Finally, presenting another manipulable distractor object at the T1 + 1 position eliminated the processing benefit for congruent action recipients (Exp. 4). These last two experiments, in particular, importantly demonstrate an involvement of the motor system in the joint visual processing of tool–action recipient object pairs.

Considerable evidence now suggests that visual processing of manipulable objects elicits activation in a network of left-hemispheric structures; in particular the intraparietal sulcus, posterior middle-temporal gyrus, and ventral premotor cortex (e.g., Boronat et al., 2005; Chao & Martin, 2000; Kellenbach, Brett, & Patterson, 2003). The parietal activation in particular is thought to represent processing of the contextualized, spatio-motor properties of the object (Bach et al., 2010), and is thought to underlie a number of effects reported with manipulable objects. For example, behavioral responses to manipulable objects are affected by the congruence between the size of the grasp used to make the response and the size of the object (Ellis & Tucker, 2000) or whether the handle of an object is more available to be grasped by the responding hand (Tucker & Ellis, 2004). This later effect has also been shown to be dependent on the object being presented in "reachable space" (Constantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). Processing in this tool-related network is also thought to link tools with their potential action recipients (Bach, Knoblich, Gunter, Friederici, & Prinz, 2005; Bach et al., 2010). Indeed, Adamo and Ferber (2009) suggested that the reduced AB for action recipient T2 objects that they observed in their study may be related to processing in tool-related areas for the tool T1 objects. Our results strengthen this argument in a number of ways. Firstly, showing that the effect is specific to congruent tool–action recipient pairings rules out alternative explanations regarding salient physical differences between action recipients as a group and the nonaction objects used as targets or distractors. We also demonstrated that the tool must be presented first in order to elicit the effect. Presenting the action recipient objects first presumably does not elicit motoric activation in tool-related areas. Therefore, it provides no benefit for the subsequently presented tool. Importantly, we demonstrated that the effect is sensitive to whether the tool is positioned to act on the action recipient. Presenting the tool facing away from the action recipient did not reduce the AB beyond the special case when the two objects could be processed in the same attentional episode (i.e., at lag 1). Green and Hummel (2006) also showed that tools can prime identification of their action recipients and, similar to our results, this effect was only observed when both objects are properly aligned with each other for action. These findings fit well with the sensitivity of tool-related areas to modulations in the motoric properties of manipulable objects (i.e., their orientation with respect to the hand; e.g., Petit et al., 2006; Tucker & Ellis, 1998). Furthermore, work by Humphreys and Riddoch has demonstrated that motorically aligned manipulable objects and action recipients are more resilient to visual extinction in patients with damage to the parietal lobe (Humphreys & Riddoch, 2001; Humphreys, Wulff, Yoon, & Riddoch, 2010; Riddoch et al., 2003; Riddoch et al., 2006). Finally, we found that presenting a second tool at the T1 + 1 distractor position removed the facilitation seen for congruent action recipients. The subsequent distractor tool presumably interfered with, or replaced, the sensorimotor transformations activated by the T1 tool that are responsible for establishing the link to the T2 action recipient. This is in keeping with other findings demonstrating interference between tools with differing motor affordances associated with them (Harris et al., 2012; Helbig et al., 2006; Helbig, Steinwender, Graf, & Kiefer, 2010; McNair & Harris, 2012). It also provides the strongest evidence of the involvement of the motor system in this process, as the visual experience of the tool and action recipient objects was physically unchanged.

Adamo and Ferber (2009) suggested that the match between the action recipient and the motor affordance generated by the prior tool promotes its encoding into VSTM, in line with VSTM-weighting models of the AB (Shapiro et al., 1994). This was based on their finding of an enhanced P3 component associated with correctly reported action recipient T2s as compared to correctly reported nonaction T2s. However, this interpretation may be premature, given that the time window they examined (250–750 ms) encompasses a number of distinct cognitive processes. As we observed in the present study, action recipients as a whole (i.e., including incongruent action recipients) elicited better performance than did nonaction objects. This difference, however, was eliminated by removing the nonaction object distractors from the RSVP stream—leaving only the congruent tool–action recipient AB effect. Thus, the effects observed by Adamo and Ferber, and attributed to the P3 component and working memory encoding, may instead relate to more successful masking of the nonaction object T2 stimuli relative to action recipients. Alternatively, they may reflect P3a novelty effects related to the lower proportion of action recipients within the RSVP stream relative to nonaction objects. Further EEG work, utilizing similar experimental manipulations to those employed in the present study, would be needed to disentangle these possible alternatives.

Nevertheless, taken together, the findings of the present study support the idea that the processing of a manipulable object elicits a representation that facilitates the processing of a subsequent, action-related object. This representation is context-specific, in that it is sensitive to the contextual motoric relationship between the tool and its action recipient, and can be overwritten, or interfered with, by the subsequent presentation of another manipulable object. Our research here joins a relatively small, but growing body of research demonstrating an important cognitive link between manipulable objects and the objects that they act on.

Author note N.A.M. is now in the School of Psychology, Plymouth University, Devon, UK. This research was funded by Australian Research Council Discovery Project Grant No. DP0879206, and I.M.H. was supported by an ARC Future Fellowship (No. FT0992123). We are grateful to Jody Kamminga and Nicole De Fina for assistance in testing participants.

References

Adamo, M., & Ferber, S. (2009). A picture says more than a thousand words: Behavioural and ERP evidence for attentional enhancements due to action affordances. *Neuropsychologia, 47,* 1600–1608.

Ariga, A., & Yokosawa, K. (2008). Contingent attentional capture occurs by activated target congruence. *Perception & Psychophysics, 70,* 680–687. doi:10.3758/PP.70.4.680

Bach, P., Knoblich, G., Gunter, T. C., Friederici, A. D., & Prinz, W. (2005). Action comprehension: Deriving spatial and functional relations. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 465–479.

Bach, P., Peelen, M. V., & Tipper, S. P. (2010). On the role of object information in action observation: An fMRI study. *Cerebral Cortex, 20,* 2798–2809.

Boronat, C., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D., & Detre, J. A. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research, 23,* 361–373.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10,* 433–436. doi:10.1163/156856897X00357

Buxbaum, L. J. (2001). Ideomotor apraxia: A call to action. *Neurocase, 7,* 445–458.

Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and non-apraxic subjects. *Brain and Language, 82,* 179–199.

Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage, 12,* 478–484. doi:10.1006/nimg.2000.0635

Chua, F. K. (2005). The effect of target contrast on the attentional blink. *Perception & Psychophysics, 67,* 770–788. doi:10.3758/BF03193532

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 109–127. doi:10.1037/0096-1523.21.1.109

Constantini, M., Ambrosini, E., Tieri, G., Sinigaglia, C., & Committeri, G. (2010). Where does an object trigger an action? An investigation about affordances in space. *Experimental Brain Research, 207,* 95–103.

Di Lollo, V., Kawahara, J. I., Ghorashi, S. M., & Enns, J. T. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research, 69,* 191–200. doi:10.1007/s00426-004-0173-x

Dux, P. E., & Harris, I. M. (2007). Viewpoint costs occur during consolidation: Evidence from the attentional blink. *Cognition, 104,* 47–58. doi:10.1016/j.cognition.2006.05.004

Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology, 91,* 451–471.

Evans, K. K., & Treisman, A. (2005). Perception of objects in natural scenes: Is it really attention free? *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1476–1492. doi:10.1037/0096-1523.31.6.1476

Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics, 64,* 741–753. doi:10.3758/BF03194741

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

Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience, 17,* 2735–2740.

Harris, I. M., Benito, C. T., & Dux, P. E. (2010). Priming from distractors in rapid serial visual presentation is modulated by image properties and attention. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1595–1608. doi:10.1037/a0019218

Harris, I. M., & Little, M. J. J. (2010). Priming the semantic neighbourhood during the attentional blink. *PLoS ONE, 5,* e12645. doi:10.1371/journal.pone.0012645

Harris, I. M., Murray, A. M., Hayward, W. G., O'Callaghan, C., & Andrews, A. (2012). Repetition blindness reveals differences between the representations of manipulable and non-manipulable objects. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 1228–1241.

Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Experimental Brain Research, 174,* 221–228.

Helbig, H. B., Steinwender, J., Graf, M., & Kiefer, M. (2010). Action observation can prime visual object recognition. *Experimental Brain Research, 200,* 251–258.

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

Humphreys, G. W., & Riddoch, M. J. (2007). How to define an object: Evidence from the effects of action on perception and attention. *Mind and Language, 22,* 534–547.

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,* 659–670.

Jefferies, L. N., & Di Lollo, V. (2009). Linear changes in the spatial extent of the focus of attention across time. *Journal of Experimental Psychology: Human Perception and Performance, 35,* 1020–1031. doi:10.1037/a0014258

Juola, J. F., Botella, J., & Palacios, A. (2004). Task- and location-switching effects on visual attention. *Perception & Psychophysics, 66,* 1303–1317. doi:10.3758/BF03195000

Kellenbach, M. L., Brett, M., & Patterson, K. (2003). Actions speak louder than functions: The importance of manipulability and action in tool representation. *Journal of Cognitive Neuroscience, 15,* 30–46.

Kleiner, M., Brainard, D., & Pelli, D. (2007, August). *What's new in Psychtoolbox-3?* Tutorial session presented at the 30th European Conference on Visual Perception, Arezzo, Italy.

Livesey, E. J., & Harris, I. M. (2011). Target sparing effects in the attentional blink depend on type of stimulus. *Attention, Perception, & Psychophysics, 73,* 2104–2123. doi:10.3758/s13414-011-0177-8

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature, 383,* 616–618. doi:10.1038/383616a0

Lunau, R., & Olivers, C. N. L. (2010). The attentional blink and lag 1 sparing are nonspatial. *Attention, Perception, & Psychophysics, 72,* 317–325. doi:10.3758/APP.72.2.317

Maki, W. S., Frigen, K., & Paulsen, K. (1997). Associative priming by targets and distractors during rapid serial visual presentation: Does word meaning survive the attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1014–1034.

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin & Review, 13,* 125–131. doi:10.3758/BF03193823

McNair, N. A., & Harris, I. M. (2012). Disentangling the contributions of grasp and action representations in the recognition of manipulable objects. *Experimental Brain Research, 220,* 71–77.

Olivers, C. N. L., & Meeter, M. (2008). A boost and bounce theory of temporal attention. *Psychological Review, 115,* 836–863. doi:10.1037/a0013395

Osiurak, F., Aubina, G., Allain, P., Jarry, C., Etcharry-Bouyx, F., Richard, I., & Le Gall, D. (2008). Different constraints on grip selection in brain-damaged patients: Object use versus object transport. *Neuropsychologia, 46,* 2431–2434.

Osiurak, F., Jarry, C., & Le Gall, D. (2011). Re-examining the gesture engram hypothesis: New perspectives on apraxia of tool use. *Neuropsychologia, 49,* 299–312.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10,* 437–442. doi:10.1163/156856897X00366

Petit, L. S., Pegna, A. J., Harris, I. M., & Michel, C. M. (2006). Automatic motor cortex activation for natural as compared to awkward grips of a manipulable object. *Experimental Brain Research, 168,* 120–130.

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 979–992.

Potter, M. C., Wyble, B., Pandav, R., & Olejarczyk, J. (2010). Picture detection in rapid serial visual presentation: Features or identity? *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1486–1494. doi:10.1037/a0018730

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860. doi:10.1037/0096-1523.18.3.849

Riddoch, M. J., Humphreys, G. W., Edwards, S., Baker, T., & Wilson, K. (2003). Seeing the action: Neuropsychological evidence for action-based effects on object selection. *Nature Neuroscience, 6,* 82–89.

Riddoch, M. J., Humphreys, G. W., Hickman, M., Clift, J., Daly, A., & Colin, J. (2006). I can see what you are doing: Action familiarity and affordance promote recovery from extinction. *Cognitive Neuropsychology, 23,* 583–605.

Roberts, K. L., & Humphreys, G. W. (2011). Action-related objects influence the distribution of visuospatial attention. *Quarterly Journal of Experimental Psychology, 64,* 669–688.

Shapiro, K., Driver, J., Ward, R., & Sorensen, R. E. (1997). Priming from the attentional blink: A failure to extract visual tokens but not visual types. *Psychological Science, 8,* 95–100.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 357–371. doi:10.1037/0096-1523.20.2.357

Shih, S., & Reeves, A. (2007). Attentional capture in rapid serial visual presentation. *Spatial Vision, 20,* 301–315.

Sidak, Z. (1967). Rectangular confidence regions for the means of multivariate normal distributions. *Journal of the American Statistical Association, 62,* 626–633.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 174–215. doi:10.1037/0278-7393.6.2.174

Tibboel, H., De Houwer, J., Spruyt, A., & Crombez, G. (2011). The attentional blink is diminished for targets that form coherent semantic categories. *Acta Psychologica, 136,* 321–328.

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,* 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,* 769–800.

Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica, 116,* 185–203.

Valyear, K. F., & Culham, J. C. (2010). Observing learned object-specific functional grasps preferentially activates the ventral stream. *Journal of Cognitive Neuroscience, 22,* 970–984.

Visser, T. A. W., Zuvic, S. M., Bischof, W. F., & Di Lollo, V. (1999). The attentional blink with targets in different spatial locations. *Psychonomic Bulletin & Review, 6,* 432–436. doi:10.3758/BF03210831

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1656–1674. doi:10.1037/0096-1523.24.6.1656

Ward, R., Duncan, J., & Shapiro, K. (1997). Effects of similarity, difficulty, and nontarget presentation on the time course of visual attention. *Attention, Perception, & Psychophysics, 59,* 593–600.

Wyble, B., Bowman, H., & Nieuwenstein, M. (2009). The attentional blink provides episodic distinctiveness: Sparing at a cost. *Journal of Experimental Psychology: Human Perception and Performance, 35,* 787–807. doi:10.1037/a0013902

Yoon, E. Y., & Humphreys, G. W. (2005). Direct and indirect effects of action on object classification. *Memory & Cognition, 33,* 1131–1146.

Yoon, E. Y., & Humphreys, G. W. (2007). Dissociative effects of viewpoint and semantic priming on action and semantic decisions: Evidence for dual routes to action from vision. *Quarterly Journal of Experimental Psychology, 60,* 601–623. doi:10.1080/17470210600701007