Citation: Makris, S., Hadar, A. A. and Yarrow, K. (2013). Are object affordances fully automatic? A case of covert attention. Behavioral Neuroscience, 127(5), pp. 797-802. doi: 10.1037/a0033946

Are object affordances fully automatic? A case of covert attention.

Stergios Makris[1], Aviad A. Hadar[2], & Kielan Yarrow[2]

[1] Dipartimento di Scienze Umane, Universita degli Studi di Udine
[2] Department of Psychology, City University London

* Author for correspondence:

Dr Stergios Makris,
Dipartimento di Scienzi Umane
Universita degli Studi di Udine
Via Margreth, 3
I-33100 Udine
Italy

Tel: +39 0432 249889
Email: stergios.makris@uniud.it

Abstract

Inspired in part by Gibson’s (1979) ecological approach to perception, current neurocognitive theories of action suggest that the simple viewing of an object can automatically elicit motor programs for specific acts. However, the degree to which such affordances should be considered truly automatic is unknown. Here we explored the generation of motor plans afforded by pairs of cue objects that were viewed peripherally under different attentional states. Participants focussed centrally while attending to just one of two peripheral cue objects that together had a strong significance for pinching, grasping, or both. They were instructed to ignore the objects and instead give power or precision grip responses to subsequent changes in background colour. The data showed a significant interaction between type of response and type of object, indicating that object affordances are perceived even in non-foveal vision. Critically, the generation of affordances was modulated by the locus of attention: Motor preparation was biased towards the attended object when two different categories of object appeared in the same trial, but the generation of affordances was also influenced by unattended stimuli. This finding demonstrates that object-action priming is not completely automatic, instead being constrained by processes of perceptual selection.

Keywords: affordances, objects, attention, actions, eye-tracker

1. Introduction

Meaningful and efficient interactions with our environment require a strong relationship between visual perception and action. In view of this, Gibson (1979) proposed the concept of “affordances”, which can be interpreted as the actions that the environment permits for a particular observer (Michaels, 2003). Although the term originates in ecological psychology, affordances are now commonly discussed in the cognitive neuroscience literature (as here) without any strict adherence to Gibson’s broader theoretical position. In this literature, they are generally taken to be evidenced when the motor system responds to a stimulus in a highly automatic manner. For example, the simple viewing of an object can automatically elicit motor system activity supporting possible actions towards that object, which can be either directly recorded, or inferred from behaviour (e.g. Chao & Martin, 2000; Craighero, Fadiga, Umiltà & Rizzolatti, 1996; Tucker & Ellis, 1998). This “affordance effect” arises even when there is no intention to implement the action. Although inferences based on behavioural measures have received some criticism (e.g. Anderson et al, 2002), research evidence from neuroimaging (e.g. Grezes et al., 2003), neuropsychology (e.g. Riddoch et al., 2003) and behavioural studies (e.g. Craighero et al., 1996; Ellis & Tucker, 2000; Vingerhoets et al., 2009) collectively supports the idea that stimuli with action significance provoke the automatic preparation of relevant actions.

Focussing on the behavioural work, reaction time (RT) studies have shown that responses to visual objects are facilitated when they overlap with the actions these objects naturally afford. For example, in a seminal study Tucker and Ellis (1998) tested whether the handle position of an object would prime right and left-hand responses during an orientation-classification task. Responses were faster when the handle of the object and the responding hand shared the same side of space, even though the position of the handle was irrelevant for the experimental task. In a subsequent study, Ellis and Tucker (2000) presented objects with action significance for pinching or grasping, while participants gave responses via a device that required them to mimic power and precision grips. Precision-grip responses were facilitated by pinchable object primes and power-grip responses were faster when viewing graspable objects, despite these visual objects having no relevance for the auditory discrimination task that was being performed.

In a recent study, Makris et al. (2011) further examined the potentiation of grasping behaviours by visual objects, while additionally exploring the temporal evolution of such affordances. They used object primes with action significance for pinching or grasping, as well as neutral objects. Two different methodologies were applied, one based on RTs and the other on corticospinal excitability (assessed by applying transcranial magnetic stimulation (TMS) and measuring motor evoked potentials (MEPs)). The first experimental task involved participants viewing the stimuli briefly, then responding to background colour changes with pinching and grasping actions (similar to Ellis and Tucker, 2000). During the second experiment, participants viewed the same objects passively while receiving single-pulse TMS over their primary motor cortex. MEPs were recorded from two intrinsic hand muscles associated with a power or precision grip. In both experiments, three different stimulus-onset asynchronies (SOAs) were used to provide a time course for the development of affordances. Both RT and MEP measures implied that the generation of a congruent motor plan had occurred in the period immediately after object presentation (already evident at 300-400ms) which then rapidly decayed (by ~600 ms post stimulus).

The rapid decay of affordances identified by Makris et al. (2011) is intriguing, and could reflect the metabolic or computational costs associated with maintaining plans for action.

However, other potential explanations emerge from the specific experimental conditions used. In particular, the role of visuospatial attention must be considered. Newly appearing objects are known to automatically and exogenously grab attention (Yantis & Jonides, 1984). Furthermore, exogenous attentional cuing generates both benefits and costs across time, with such “inhibition of return” (Posner & Cohen, 1984) implying the withdrawal of attention to facilitate subsequent visual search. This pattern is of obvious relevance to the activation and dissipation of affordances observed by Makris et al. (2011).

The role of attention in affordances is explicitly acknowledged within at least one recent model (the affordance competition model; Cisek, 2006). Indeed, while the affordance concept might be taken to imply the simultaneous generation of an overwhelming multitude of motor plans, mechanisms of selective attention could prevent such overload. Somewhat surprisingly, however, the interplay of attention with the generation of affordances has received little attention to date (but see Ellis et. al, 2007; Murphy, van Velzen & de Fockert, 2012). Work linking attention with affordances has been carried out, but it has tended to focus on either the way objects and affordances might drive the allocation of attention (e.g. Roberts & Humphreys, 2011b) or, somewhat relatedly, the role of attention as a possible confound in experiments investigating affordances via stimuli with lateralised handles (e.g. Anderson et al., 2002; Cho & Proctor, 2010; Riggio et al. 2008). Here, we instead consider the extent to which affordances develop for objects appearing inside and outside the locus of covert visuospatial attention.

To this end, we used the experimental designs of Ellis and Tucker (2000) and Makris et al. (2011) in which participants were required to give power or precision grip responses to an arbitrary stimulus presented alongside object primes. Whereas most previous studies have investigated the affordance effect for centrally located stimuli, we instead applied a covert attention paradigm with pictures of objects viewed peripherally. More specifically, we presented pictures of pinchable and graspable objects in *both* hemifields while participants focussed on a central fixation cross. Subjects attended to either the left or right side and responded to colour change occurrences. Hence we applied a classic endogenous attention paradigm (c.f. Posner, 1980, but here based on a 100% valid cue). We expected the pragmatic properties of visual objects to activate specific motor plans, evidenced as a response/object congruency advantage. The methodology applied allowed us to additionally demonstrate that affordances are modulated by the allocation of attention.

2. Methods

2.1. Participants

The study was approved by the City University London Psychology Department Ethical Committee in accordance with the ethical standards of the Declaration of Helsinki (1964). We tested 20 naïve participants (11 females; Mean age = 24, SD = 5.2), all assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and all right-handed (Mean Lateralization index (LI) = 0.93, SD = 0.18). All participants reported normal or corrected to normal vision.

2.2. Material/Apparatus

The stimulus set consisted of 10 objects; 5 associated with a power grip and 5 associated with a precision grip (Appendix A). Coloured pictures of all objects were taken and presented in approximately their natural size (9.6º to 11.3º visual angles for “pinchable” objects and 14.8º to 15.2º for “graspable” objects) within a background rectangle (typically larger than the object being presented by ~ 6º). All pictures of objects were presented peripherally (with the middle of the objects always at 14.2º temporally) on a 19-inch LCD screen (refresh rate 60 Hz). Objects appeared with no obvious intrinsic left/right orientation (i.e. oriented with their handle, if present, positioned near the vertical). Pictures of these pinch-grip and power-grip objects on a white background served as primes and pictures of the same objects on a subtle yellow or blue background were the targets (i.e. participants responded to a change of colour). The response device was adapted from Ellis and Tucker (2000). It consisted of a plastic cylinder, at the top of which a small pressure button was attached, and a small plastic pressure switch that was taped to the inside tip of the participant’s thumb. Participants held the device with their dominant hand, pinching the switch with their index finger and thumb, and grasping the cylinder with the remaining three fingers against the palm. In this way, responses with the cylinder or the switch mimicked power or precision grips respectively.

2.3. Eye tracker

We were interested in the allocation of *covert* spatial attention towards objects viewed peripherally. Hence, a chinrest-mounted video eye-tracker was employed to ensure participants maintained central fixation (Model C6, Applied Science Laboratories, Bedford, MA; sampling rate = 125Hz, calibrated manually using a nine-point fixation stimulus).

2.4. Design & Procedure

<INSERT FIGURE 1 AROUND HERE>

The experiment was controlled by a PC running E-Prime Software version 1.1 (Psychology Software Tools, Inc., Pittsburgh, PA, 2002). A second PC running Eye-Trac 6 .Net User Interface (Applied Science Laboratories, Bedford, MA) recorded eye-tracker measurements. Participants were seated comfortably at a distance of 50 cm from the computer screen (maintained with a chin rest). After briefly demonstrating how to hold and use the response device, a short practice session commenced (approximately 30 trials).

In the experiment, participants were asked to fixate a centrally located cross, while attending to either the left or right side of the screen for the response targets (blocked, with order counterbalanced across participants). Each trial started with the fixation cross on screen for one second, after which two prime (object) stimuli appeared on a white background to the left and right. There were four different conditions: Pinchable objects at both the left and right side ("same pinchable" condition); graspable objects at both the left and right side ("same graspable"); pinchable object at the left side and graspable object at the right side ("mixed PG"), and vice versa ("mixed GP"). The SOA between the prime objects and the response target was 500 ms. The response target was a subtle change in one of the primes' background colour (to either blue or yellow), always on the attended side. Half of the participants pressed the cylinder for a blue colour change and the small switch for a yellow target, with mapping swapped for the other half. The target remained visible until the participant gave a response, at which point the next trial commenced. Overall there were 400 trials (2 blocks, attending to left/right sides, x 4 conditions x 2 targets x 25 combinations of the five possible objects on the left and the five possible objects on the right). Each participant received a different random ordering. After the end of the experiment all participants were debriefed and compensated.

2.5. Data analysis

All data were processed offline using Eye-Trac 6 .Net User Interface (Applied Science Laboratories, Bedford, MA), E-Data Aid Software version 1.1 (Psychology Software Tools, Inc., Pittsburgh, PA, U.S.A., 2002) and Microsoft Excel (2007 edition). The eye-tracker software recorded X-Y gaze co-ordinates. We inspected these for a time period of one second post stimulus presentation (by synching the clocks of both computers using a common internet source at the start of each session). Trials containing saccades (an eye movement with ≥3.4º excursion from the fixation point) were removed from the analysis. The trial removal rate for all participants was less than 10%. Response errors were logged when the response (power or precision grip) was incorrect based on the background colour change. All participants showed an error rate of less than 10%. The median of reaction times (RTs) was calculated using only correct trials for each participant in each condition. These data were then submitted to a repeated-measures analysis of variance (ANOVA) with attention side (left, right), type of response (power grip, precision grip), object-type presentation condition (same, mixed) and response congruence to the type of the attended object (congruent, incongruent; i.e. a power-grip response to an attended graspable object was considered as congruent) as within-subjects factors. An identical analysis was performed on mean error rates across the different experimental conditions, but showed no significant main effects or interactions, and no trend indicative of a speed-accuracy trade off, so is not reported here.

3. Results

<INSERT FIGURE 2 AROUND HERE>

In experiments of this kind, affordance effects are usually reported as an interaction between the type of response that is being made and the type of object that is being displayed. To simplify our presentation, here we instead selected an alternative coding of the conditions (as specified in the data analysis, above) in order to generate a single experimental factor representing the match between the object presented *at the attended location* and the response that was made.[1] Thus we assessed congruence as a main effect, and investigated how it interacted with our other experimental manipulations. Because attention-side and response-type did not yield main effects or interactions in our analysis we collapsed these factors to further simplify the presentation of the results.

Our ANOVA showed that the interaction between object presentation condition and congruence (with congruency representing a match between the response and the object at the attended location) was significant [F (19, 1) = 7.54; p = 0.013; $\eta^2 = 0.28$]. Also, there was a significant main effect of congruence [F (19, 1) = 52.06; p < 0.001; $\eta^2 = 0.73$]. Given the significant two-way interaction and the fact that there were no other significant main effects or interactions, we decided to collapse our data for the attention-side and response-type factors (see Figure 2). Post-hoc paired t-tests revealed that congruent responses (M = 460, SD = 73) were significantly faster than incongruent responses (M = 512, SD = 83) for the same-

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[1] Note that the particular choice of factorial coding does not influence effect sizes in any way; it simply allows us to convert what would, under a more traditional coding, be a four-way statistical interaction, into a main effect (which is much easier to graph, and also easier to understand in interaction with other factors).

object presentation condition [t (19) = 7.5; p < 0.001]. Also, congruent responses (M = 491, SD = 81) were significantly faster than incongruent responses (M = 505, SD = 88) for the mixed-object presentation condition [t (19) = 2.89; p = 0.009]. Finally, congruent responses for the same-object presentation condition (M = 461, SD = 73) were significantly faster than congruent responses for the mixed-object presentation condition (M = 491, SD = 81) [t (19) = 2.18; p = 0.042], but there was a non-significant trend in the opposite direction for incongruent responses, driving the interaction in the ANOVA.

4. Discussion

Our experiment revealed that responses were quicker when the object at the attended location matched the response that was being made, be it a precision or power grip. Most importantly, even for the mixed-object presentation conditions, in which objects of both types were presented, responses congruent to the object at the *attended* location were facilitated. However, in this case the affordance effect was not as strong as for the same-object presentation conditions, and thus we can infer that unattended objects also affected the responses: Attentional selection drove the generation of affordances, but unattended objects still exerted some influence on the motor system.

To expand on this interpretation: The data analysis illustrates that congruent responses were faster than incongruent responses for conditions of both same-object and mixed-object presentation, but that this effect appears magnified for same-object conditions. To understand this result, consider what was occurring in each condition. In same-object conditions, the attended object was accompanied by an identical object opposite the locus of attention. Hence, in the absence of attention, we might think of the comparison as being between *double* congruent and double incongruent object presentations. The RT difference thus demonstrates how affordances were generated despite the fact that objects appeared in the periphery. In mixed-object conditions, by contrast, one object of each type was being presented, implying that in the absence of attention both responses would be equally primed, so no differential affordance effect would emerge. The fact that an effect does emerge suggests that the object at the attended location received higher weight in the generation of affordances, demonstrating attentional modulation. However, the fact that the congruence effect appears smaller here relative to the same-object conditions implies that the object at the unattended location must also have been having some effect, either boosting the generation of the affordance in the same-object condition, counteracting it in the mixed-object condition, or both. Note that our data do not indicate whether the influence of this unattended object was discrete (i.e. it resulted from this object having captured attention on a subset of trials despite the overall task set) or was more uniform in nature (i.e. some influence of the unattended stimulus was reaching the motor system on *all* trials).

These results are in broad accordance with findings from previous studies concerning the generation of affordances via object priming (Ellis and Tucker, 2000; Makris et al, 2011; Tucker & Ellis, 2001). More specifically, Ellis and Tucker (2000) found that participants' power and precision grip responses to an irrelevant auditory stimulus were faster when viewing objects with significance for congruent actions. These results were further confirmed in our previous study (Makris et al, 2011), which demonstrated how visual objects potentiate congruent motor programs even in cases where there is no intention to execute the motor command.

The importance of the present results lies in the methodology applied for examining the generation of affordances by viewing objects with action significance under different states of attention. Unlike many previous studies (i.e. Ellis & Tucker, 2000; Makris et al, 2011; Tucker & Ellis, 1998, 2001) that used centrally located stimuli as primes, we had the participants viewing and responding to objects perceived using a covert form of visual attention. This means that objects presented away from the fovea and thus processed with lower resolution with regards to their physical characteristics were still able to excite the motor system into producing programs for relevant actions.

A previous study by Ellis et al (2007) applied a somewhat similar methodology in order to investigate the involvement of action codes in object-level selection. More specifically, they tested how in multiple-object displays the presence of distractors facilitated or inhibited responses to relevant targets (see also Pavese & Buxbaum, 2002). In four different experiments they presented at the same time pinchable and graspable objects and they asked participants to respond to a simple geometric property via a device that permitted the measurement of power and precision grips. Target and distractor objects were displayed either close to each other or at distant spatial locations. Participants were instructed to identify the target either by a colour feature or by a specific spatial location. The results showed that the presence of object-distractors *impaired* compatible responses whenever participants had the chance to attend and overtly perceive their physical properties (i.e. when the target was indicated by the colour, requiring an initial selection process on every trial). However, this inhibition effect was not obtained when participants did not have to consider the distractor in order to identify the target (i.e. when the target was always presented at the same location). In the present study it was found that *positive* affordance effects could be generated in cases of mixed-object presentations, with unattended stimuli affecting responses.

Hence, contrary to the observation of Ellis et al (2007), in our study unattended stimuli induced compatible motor response codes. It may be that their interference effect was specific to conditions in which the distractor must be processed and then de-selected.

There are also some other important methodological differences between the present study and the one described by Ellis and his colleagues. In 3 of their 4 experiments participants viewed both the target and the distractor overtly (i.e. by fixating them) whereas in our study stimuli were always perceived covertly. Furthermore, in the experiment for which they reported no evidence of an inhibition effect, the target was always perceived overtly and the distractor was peripherally displayed, thus visual acuity was not equally dispersed between the stimuli. The present study managed to obtain effects from unattended objects, but in this case both attended and unattended stimuli were perceived covertly. Overall, we would suggest (with due diffidence) that the methodology described here had a better control over the attentional conditions under which affordance effects were generated, and hence we managed to present evidence of affordances extracted from unattended objects.

We are aware of only one other study that has directly addressed how attention to object primes can affect the degree to which those objects generate affordances whilst controlling overt attention. Murphy, van Velzen and de Fockert (2012) chose a quite different approach for modulating attention to that used here. They varied the degree of “perceptual load” (see Lavie, 2005, for review) for a letter identification task performed at fixation. At the same time, they assessed congruency effects from peripheral prime objects with left/right oriented handles on a left/right hand button-press response. Consistent with the results we have presented, they found a congruency effect of peripheral objects on responses, but only when central perceptual load was low, permitting attention to spill into the periphery. Our results complement theirs nicely; whereas they tested situations varying from almost zero attention (high central load, object not at the locus of attention) to limited attention (low central load, object not at the locus of attention), we have shown continued attentional modulation as we move from limited attention (object not at the locus of attention) to full attention (object at the locus of attention).

Like the study of Murphy, van Velzen and de Fockert (2012), our study suggests that objects potentiate associated action plans, but to a degree that depends upon how much attention they are receiving. Such a process could be considered as improvident, since in general we are surrounded by a multitude of objects that draw our attention directly or indirectly. This should result in the formation of many motor plans for actions that will never be implemented. One possible theoretical reason to explain such a “waste” of resources is that this generation of motor programs to deal with a multitude of contingencies can result in a crucial speed advantage for relevant actions (Yarrow et al, 2009). Moreover, Cisek (2006, 2007) has incorporated this notion into a theory of motor decision making known as the “affordance competition” hypothesis. According to this theory, attended visual stimuli automatically elicit the generation of motor plans across visuo-motor regions. In order for a single motor plan to then “win” and be expressed as action, a neural mechanism of mutual inhibitory connections and biasing inputs from decision centres takes over to drive selection. Theories like this are a fundamental departure from more serial architectures in which attention gates perceptual information to inform decision making, which occurs *prior* to the generation of plans for action. Our results provide concrete support for the inclusion of attentional selection in the affordance competition model.

In conclusion, this study provided evidence for the existence of an affordance effect and suggested that affordances still develop even in cases of covert attention, with attention partially modulating their generation. Our results suggest that object affordances are automatically perceived even in non-foveal vision, but to a greater extent under circumstances that allow an adequate processing of their physical characteristics, such as when covert attention is directed towards an object. This finding places important constraints on the degree to which affordances can be considered fully automatic, and thus impervious to the operation of other psychological processes.

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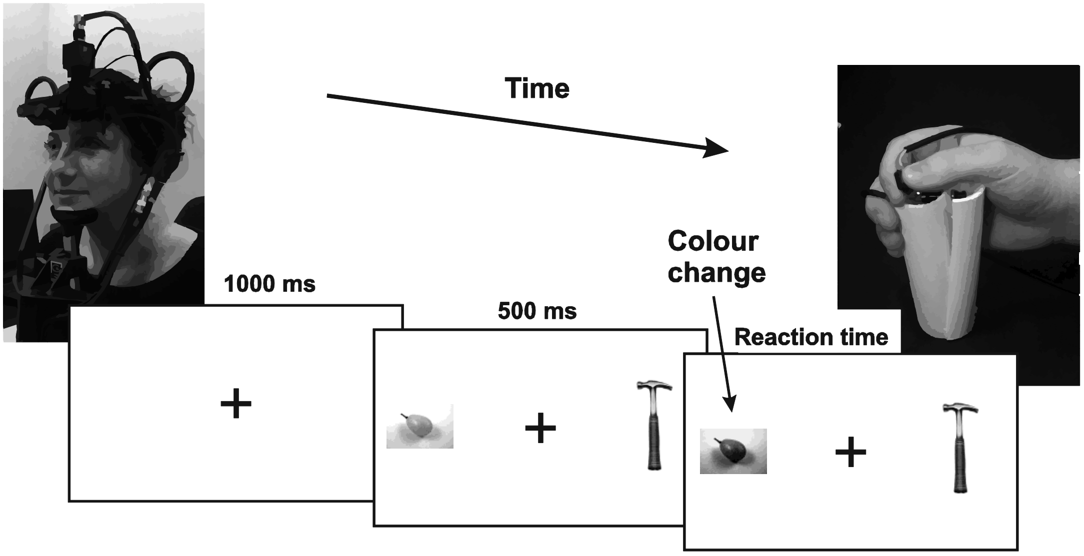
Appendix A

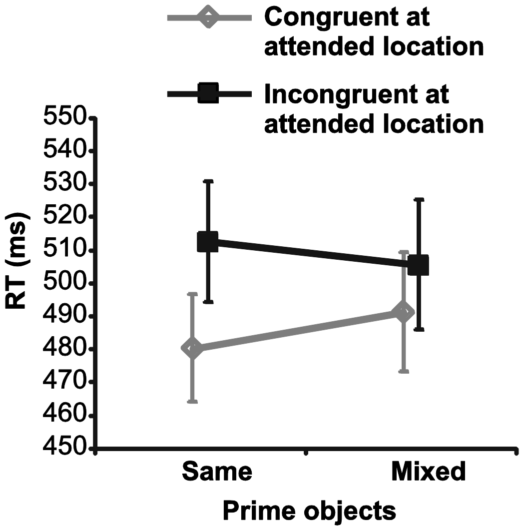
List of the objects used to form the stimuli set.

Graspable objects	Pinchable objects
Crystal glass	Grape
Hammer	Screw
Wooden brush	Plug
Thermos mug	Key
Spanner	Pencil sharpener



Legend to Figure 1.

Sequence of presentation in a typical trial (here, a mixed PG trial in the attended left block).



Legend to Figure 2.

Means of median response times, with conditions collapsed as determined by the overall ANOVA (see main text) to reveal the critical interaction between congruency and presentation condition. Error bars denote standard errors.