Micro-affordance: The potentiation of components of action by seen objects

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It is suggested that seen objects potentiate a range of actions associated with them, irrespective of the intentions of the viewer. Evidence for this possibility is provided by the data from two experiments, both of which required a participant to make a binary motor response to an auditory stimulus. In the first experiment the response was a power or precision grip, which was performed whilst simultaneously viewing a real object which would normally be grasped using either a power or precision grip. A significant interaction of response and grip compatibility of the object was observed. Similar results were obtained in the second experiment when a wrist rotation of a given direction was used as a response, whilst viewing objects which would require wrist rotations if they were to be grasped.

The effects of the seen objects on components of action are described as micro-affordances which are said to be dispositional states of the viewer’s nervous system.

The information-processing tradition tends to constrain thinking about the relations between visual objects and actions on them. An emphasis on the exchange of information between modular systems results in the conception of the visual system as a device for deriving general purpose descriptions, or representations, of the visual world, which are useful to the viewer (Marr, 1982), but used by other systems. In the case of visually guided behaviours, actions are derived from a goal state and the relevant visual information is derived by the visual system. For instance I am thirsty, therefore I plan to pick up the wine glass, and the appropriate properties, such as its location and its shape are provided by my visual system. Their particular values, computed within the visual system, are used by the action system in the control of the direction of reach and the hand shape needed to grasp the glass.

In contrast, an account may be developed in which the distinction between visual representation and the control of actions is greatly diluted. It has been suggested (e.g. Ellis, 1985, and Ellis & Tucker, 1996) that the representation of a visual object includes not only a description of its visual properties, but also encodings of actions relevant to that object. For example, a mental representation of a wine glass is, at least in part, constituted by its making available reaching and grasping, and all the other things one has learnt to do with a wine glass! This is intended to be taken quite literally, the representation of an object potentiates all the actions associated with it,

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including ones not appropriate given an agent’s current goals, and that potentiation is intrinsic to its representation. This theoretical conjecture is meant to be a solution to the symbol grounding problem (Harnad, 1990). It establishes a relationship between mental representations and the world, which endows the representations with their content. It also has empirical consequences, and those are the concern of this paper.

Ungerleider and Mishkin (1982) first suggested a functional distinction between two major parts of the visual system, which have subsequently come to be dubbed the what and where systems. The ventral pathway, projecting from primary visual cortex to the inferotemporal lobe, is referred to as the ‘what’ system because of its association with object recognition or pattern discrimination. The dorsal pathway, from primary visual cortex to the posterior parietal cortex (ppc), in contrast, was described as the ‘where’ system, because of its involvement in processing spatial aspects of objects. Neuropsychological evidence for the distinction is that lesions in the inferotemporal lobe are associated with the problems of object recognition found in visual agnosics, whilst damage to the ppc is associated with impairments of spatial processing, such as visual neglect and optic ataxia. More recent data of this sort have suggested a different and broader role for the dorsal pathway, to do with the control, or representation, of object-related actions (Goodale & Milner, 1992; Goodale, Milner, Jakobson, & Carey, 1991; Milner & Goodale, 1993).

In an intact brain a seen object brain a seen object elicits simultaneous activation in the dorsal and ventral visual, and other, systems. In the theory of object representation under scrutiny here it is this conjoint activity, in visual and action-related units, that codes objects. If, in this way, the mental representation of a visual object or property represents by virtue of its causal role in producing behavioural outputs, then a currently represented object should have observable effects on behaviour or behavioural control systems. More specifically activation, at a sub-threshold level, might be expected in the motor systems involved in various behaviours associated with the object. Whatever an observer’s intention with regard to a seen object might be, some effects on concurrent behaviour, of merely potential actions in relation to the object, might be found.

There is in fact a body of evidence for the facilitation of responses by task-irrelevant aspects of a visual stimulus. Stimulus-response compatibility (SRC) effects are often reported in forced choice reaction time experiments (see Allusi & Warm, 1990 for a review). In the simplest case a performance benefit is obtained whenever there is a match between an aspect of the stimulus and an aspect of the response. For instance, when participants indicate whether a stimulus appeared on the right or left (with position being relative), faster and more accurate responses are obtained when left presentations are indicated by the left hand, and right presentations by the right hand, compared to the reverse mapping. More significantly for our purposes here, SRC effects are observed even when the relationship is between a response and an aspect of the stimuli which is not at all relevant to the task, as in the ‘Simon effect’ (Simon, 1969). An example is that when participants make bimanual responses according to the colour or shape of stimuli, performance is facilitated if the position of the hand of response is congruent with the relative position of stimulus presentation.
The Simon effect suggests that stimulus properties give rise to appropriate response codes. Even when the response to be made is known, but delayed until a go/no go signal is presented, responses are effected by the location of the latter signal (Hommel, 1995). The automaticity of response code formation, within the SRC paradigm, is supported by electro-physiological data. Both evoked potentials (Eimer, 1995) and single cell recordings (Requin & Riehle, 1995) show that task-irrelevant spatial location information elicits a congruent spatial response code.

Is location the only feature of a visual object that elicits action-related response properties, irrespective of goal? If the conjecture concerning the representation of visual objects, sketched above, is sound, other action-related features, such as size, shape and orientation, should have similar effects. Tucker and Ellis (1998) investigated this possibility. Pictures of objects were presented for participants to judge whether they were shown in a normal or inverted vertical orientation and to respond accordingly with a left or right-hand key press. The objects were also depicted in one of two horizontal orientations, differing in terms of which hand would be optimal to use to actually reach and grasp the object in that orientation. For instance, a teapot could be presented with its handle to the viewers’s left or right. Despite the irrelevance of horizontal orientation to the task it affected the key press responses. If the hand of response was the same as the optimal hand for reaching and grasping, implicit in the horizontal orientation, participants were faster and more accurate, compared to the incongruent case. Their account of these data, and some other observations reported in the SRC literature, is that a seen object affords the actions it is associated with. Smallish objects within arms’ reach, like those depicted in the photographs used in the Tucker and Ellis experiments above, afford grasping, among other things. Moreover they afford a particular kind of grasp. Features of the object such as its location, shape and orientation will lead to activation of specific components of a reaching and grasping action. Particular directions of reach, particular hand shapes and particular hands will be facilitated by the sight of an object within reaching space. These potentiated components of a grasping response are referred to as micro-affordances. We will discuss the idea, its relationships with other notions of affordance and theories of stimulus–response compatibility, in the general discussion at the end of this paper, having described a series of experiments which provide further illustrations of their effects.

If it is the case that at least some compatibility effects are to do with the micro-affordances¹ that all objects provoke regardless of the observers’ intention, then similar effects should be observable for other components of actions. The two experiments reported in this paper were intended to investigate whether this is so. They examined the effects of seen objects on a response being made to an entirely different, auditory, stimulus. The experiments were concerned with two different types of micro-affordance. The first with the distinction between power and precision grips (Expt 1) and the second with the wrist rotation needed to align the hand for grasping an object (Expt 2). The stimuli were real objects.

¹ Here and throughout the paper we adopt a convention of using the term object compatibility to refer to the relations between a visual object and associated actions; the term compatibility effects to refer to the interaction between object compatibility and a response; and the term micro-affordance to refer to the postulated state of the observer that gives rise to these effects.
EXPERIMENT 1

Small objects such as coins and pens tend to be handled with a precision grip, with the object held between the index finger and thumb. In contrast, larger objects, such as bottles and tennis balls, are usually held with a power grip between the palm and the fingers. If the claims regarding micro-affordance are valid, the sight of an appropriate object should afford hand shape of this sort. This first experiment investigated this possibility by observing the effects of real, visual objects on the responses to an auditory tone. Participants identified the tone as high or low by making a precision or power grip, and the effects of the simultaneously present visual object on these responses were observed.

In these circumstances various compatibility effects might be expected. First, one type of mapping of response to tone might be preferred, similar to the Tucker and Ellis (1998) finding that responding to an upright object with a right-hand key press, and an inverted object with a left-hand key press was easier than the converse mapping. Second, there is the possibility of stimulus to stimulus compatibility resulting from the simultaneous visual and auditory stimulation (Kornblum & Lee, 1995). A tendency to associate high pitch sounds with small objects and low pitch sounds with large objects has been observed in both synesthetic and normal individuals (Marks, 1974, 1975). Third, and most significantly, there may be compatibility between the visual object and the grip response. Such effects are our major concern here, and their existence will be taken as evidence for micro-affordance. Note that not all objects are expected to facilitate one of the two responses. Only some objects, which have a sufficiently strongly associated or optimal grip, will differentially affect response. The discovery of such objects will be regarded as an existence proof of action potentiation from the mere sight of an object and therefore indirect evidence for micro-affordance of grip type.

Method

Participants

There were 40 participants. All were students at the University of Plymouth and received £3 or course credit for their participation. All the participants were right-handed by self-report and naive as to the purpose of the study.

Apparatus and materials

The stimuli consisted of 40 common objects listed in Table 1. Twenty of the objects had large opposition axes, such as a hammer or bottle, and would therefore normally be grasped using a power grip with the lower phalanges of the fingers opposing the palmar surface. The other 20 objects were all small, relative to the hand, or had thin principal axes such as a bottle lid or a pen, and would require grasping by a precision grip between the top most phalanges of the index finger and thumb. The stimuli were presented in a box with a one-way glass viewing screen. Objects were placed in the box by the experimenter, who followed a presentation sequence displayed on a computer screen out of sight of the participant. Between trials two lights inside the box were off, and a light above the viewing glass was on. In these circumstances participants could not see into the presentation box. Objects were displayed by switching from the external to the internal lights. The response device had two components. The
first was an aluminium cylinder, 11 cm tall and 1.8 cm in diameter. Attached to the side of the cylinder was a small section of aluminium tubing. It was hinged to the top of the cylinder and attached to a pressure switch at the base of the cylinder. It thus acted as a lever that caused the pressure switch to trigger when the hand squeezed the cylinder. The second component consisted of a pressure switch 1 cm square and 4 mm thick that was taped to the inside tip of the participant’s thumb. Participants held the device in their right hand, grasping the pressure switch between their thumb and forefinger, and the cylinder between the surface of the palm and the remaining three fingers, thus mimicking power and
precision grips. This two-component response device is illustrated in Fig. 1.

### Table 1. A list of the stimuli used in Expt 1

<table>
<thead>
<tr>
<th>Objects compatible with a precision grip</th>
<th>Objects compatible with a power grip</th>
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<tbody>
<tr>
<td>Screw</td>
<td>Hammer</td>
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<tr>
<td>Matchbox</td>
<td>Saucepan</td>
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<tr>
<td>Screw</td>
<td>Large jar</td>
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<tr>
<td>Nail</td>
<td>Claw hammer</td>
</tr>
<tr>
<td>Match</td>
<td>Frying pan</td>
</tr>
<tr>
<td>Screw</td>
<td>Large screw driver</td>
</tr>
<tr>
<td>Pencil sharpener</td>
<td>Wooden mallet</td>
</tr>
<tr>
<td>Washer</td>
<td>Rolling pin</td>
</tr>
<tr>
<td>Pen top</td>
<td>Wire brush</td>
</tr>
<tr>
<td>Coin</td>
<td>Bottle</td>
</tr>
<tr>
<td>Key</td>
<td>Metal tube</td>
</tr>
<tr>
<td>Rubber</td>
<td>Saucepan</td>
</tr>
<tr>
<td>Safety pin</td>
<td>Dust pan</td>
</tr>
<tr>
<td>Clothes peg</td>
<td>Frying pan</td>
</tr>
<tr>
<td>Bolt</td>
<td>Coffee pot</td>
</tr>
<tr>
<td></td>
<td>Metal cylinder</td>
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<tr>
<td></td>
<td>Wooden mallet</td>
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</tbody>
</table>

### Procedure

Participants were told that the experiment involved two tasks—a choice reaction time task and a recognition memory task. A small red light suspended above the glass screen was used as a warning cue. It was seen as a reflection at, approximately, the position on the glass under which the objects would appear. At the beginning of each trial it came on for 1 second, was then turned off and the light inside the stimulus box came on after an interval of 400 milliseconds. The object remained illuminated until participants responded in the manner described below. Participants were instructed to pay close attention to each object but not to rehearse previous ones. It was explained that the memory task which was to take place halfway through the experiment and at the end was of recognition and not recall, and that simply making sure they viewed each object whilst the light was on was sufficient. After 700 milliseconds exposure of the object a high or low pitched tone sounded and participants had to make either a power or precision grip response depending on the mapping rule given to them at the start of the experiment. Each participant used only one mapping rule for the entire experiment (either high pitch—precision grip/low pitch—power grip or the reverse). The tone sounded until a response was made or 3 seconds had elapsed. They were instructed to respond as fast as possible whilst remaining accurate, aiming for an error rate of less than 10%. Incorrect responses were immediately followed by a 800-millisecond beep from the computer that was approximately halfway in pitch between the two tones used to cue the responses. In summary, a trial consisted of the presentation of an object which the participant memorized, followed, after 700 milliseconds, by a tone which participants categorized with a precision or power grip response. This latter response was timed.

Each of the 40 objects was presented, in randomized order, twice in both halves of the experiment. After the first 80 trials the recognition test was carried out. Participants were told that an object would be exposed for a brief (20 milliseconds) duration in the same location as before and they had then to say whether or not they recognized it. Twelve recognition trials were given in which half of the objects had been previously viewed by the participants and half had not. These were picked at random by the

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2 In fact the power grip could not include the index finger because the index finger and thumb were used in the precision grip. However, the power grip that resulted closely resembled a typical one.
experimenter. The recognition task was repeated at the end of the experiment using a different subset of stimulus objects. The experiment thus consisted of 160 choice reaction time trials and 24 recognition trials. At the beginning of the experimental session participants were first allowed to hear examples of each tone and then given practice trials, making choice responses to the tones depending on the mapping rule assigned to them. After 15 such trials they were given further trials until they made 10 consecutive correct responses. This practice procedure was then followed by 10 practice trials of the actual task. The trials proceeded automatically with an inter-trial interval of 5 seconds during which time the experimenter placed the next object in the stimulus box.

Results

Response times

Analysis by participants. The data from two participants were discarded as their error rates exceeded 10%. For the rest, their condition means were computed after discarding reaction times more than two standard deviations from their overall means. These data were subjected to a mixed ANOVA with the within-participants factors object compatibility (precision or power) and response (precision/power) and the between-participants factor mapping rule (high tone precision/low tone power) or the reverse. This analysis revealed significant main effects of response and mapping. Precision grip responses ($M = 398.7$) were executed faster than power grip responses ($M = 417.6$), ($F(1,36) = 12.94$, $p = .001$). The main effect of mapping revealed that the assignment of the high pitched tone to precision grip responses and the low tone to power responses resulted in faster response times ($M = 380.4$) than the reverse mapping ($M = 435.9$), ($F(1,36) = 4.57$, $p = .039$). These two factors interacted as shown in Fig. 2. The pattern of the interaction suggests that there was still an important main effect of mapping, but that the main effect of response was largely attributable to an advantage for the precision grip responses in the high tone precision/low tone power mapping ($F(1,36) = 8.43$, $p = .006$).

![Figure 2. Mean reaction time (RT) showing the response by mapping interaction for Expt 1.](image-url)
The most important result, however, was that the predicted interaction between object compatibility and response was significant \((F(1,36) = 7.1, \ p = .011)\). This effect is illustrated in Fig. 3 in which it can be seen that precision grip responses tended to be executed faster \((M = 396.7)\) to objects compatible with a precision grip than to those compatible with a power grip \((M = 400.8)\). In contrast power grip responses tended to be faster in the presence of objects compatible with a power grip \((M = 410.1)\) than in the presence of objects compatible with a precision grip \((M = 425.1)\).

![Figure 3. Mean reaction time (RT) and percentage errors for Expt 1 by response and object compatibility.](image)

The interpretation of the compatibility effect is complicated by a highly significant three-way interaction between this and mapping \(F(1,36) = 17.23, \ p < .0001\). This is displayed, broken down by mapping, in Fig. 4. As can be seen from a comparison of the graphs in Fig. 4 the compatibility effect appears to be confined to the precision response to high tone mapping. Analysis of the simple interaction effects broken down by mapping showed that the response by object compatibility effect for the precision response to high tone mapping was highly significant \((F(1,18) = 19.52, \ p < .0001)\) whereas for the power response to high tone mapping a different pattern of contrasts were observed, but these did not approach significance \(F(1,18) = 1.36, \ p = .259\).

**Analysis by materials.** Analysis of the data with objects as a random factor revealed a similar pattern of effects as that of the participants analysis. The main effects of response \((F(1,19) = 33.49, \ p < .0001)\) and mapping \((F(1,19) = 336.1, \ p < .0001)\) were highly significant. The predicted interaction between response and object compatibility was significant \((F(1,19) = 10.91, \ p = .002)\). As in the participants analysis, the interaction between response and mapping was also significant \((F(1,19) = 18.64, \ p < .0001)\), as was the three-way interaction between response, object compatibility and mapping \((F(1,19) = 18.63, \ p < .0001)\). All the effects showed identical patterns of means to those shown for the participants analysis. Calculation
of $F_{\text{min}}$ for the predicted interaction between response and object compatibility gave a significant result ($F_{\text{min}}(1,70) = 4.31$, ($F(0.05, 1.70) = 4.00$)).

**Error rates**

These data were subjected to a mixed ANOVA, which indicated no significant effects. As can be seen in Fig. 3 no speed–error trade off was apparent in the case of the important response by object compatibility interaction.

**Discussion**

As expected there was a mapping effect: participants found it easiest to pair a high tone with a precision grip and a low tone with a power grip. The basis of this effect may be the association, which we noted above, of small objects with high tones and large objects with low tones (think of mice and elephants). This association may be chained with grip size. Its precise foundation should not detain us here however, as it is the relations between the visual objects and responses which have the central theoretical implications.

The significant interaction between the type of grip used to classify the auditory tone and the grasp compatibility of the visual objects, observed in one of the response to tone mappings, is a further striking example of micro-affordance. Here the compatibility is not, as in the previous case (Tucker & Ellis, 1998), between aspects of an object, and the responses made to it, but between an object and the responses made to an entirely different aspect of an observer’s environment. Like the previous case, however, there is no simple relation between the visual objects and the power/precision grip dimension. This differentiates it from the Simon effect in which a single, fixed visual dimension (location in the visual field) effects the hand of response. What aspect of an object signals a particular hand shape varies across the
set of stimuli used in the experiment. A plausible account of the effects, to us at least, is that the objects potentiated components of actions with which they were associated.

The interaction of the compatibility effects with the response mapping rule of course complicates the account. The compatibility effect is confined to the mapping of precision grip to high tone and power grip to low tone. This mapping was also the easiest, producing faster reaction times. There is evidence that action codes decay following stimulus onset (Hommel, 1994a, 1994b). Perhaps the longer reaction times in the harder mapping allowed decay of the action potentiation. Alternatively perhaps the differential mapping effect arose from the stimulus to stimulus compatibility, predicted above, in the following way.

The tendency to associate high pitch sounds with small objects and low pitch sounds with large objects (Marks, 1974, 1975) will introduce, in the circumstances of our experiment, stimulus to stimulus compatibility between the simultaneous visual and auditory stimulation (Kornblum & Lee, 1995). This in fact fits well with the observed pattern of data. One would expect the stimulus to stimulus compatibility to make an asymmetric contribution to performance in the two mappings. In the case of the precision–high/power–low combination, the stimulus to stimulus compatibility is entirely congruent, in all the conditions, with the object to response compatibility. For instance, when responding to a high tone, in the presence of a precision grip object, both the response and the tone are congruent with the seen object. In the other mapping (precision–low/power–high) the two sources of compatibility are incongruent, again in all conditions. For instance, when responding to a low tone, in the presence of a power object, the response is incongruent with the object, but the tone and object are congruent. In summary the stimulus to stimulus compatibility may contribute to the visual object to response compatibility effect in one mapping and conceal it in the other.

The data of Expt 2 will suggest which of the two accounts of the mapping effect is the more likely and is concerned with another component of reaching and grasping.

**EXPERIMENT 2**

Another component of a reach and grasp action is the rotation of the wrist required to align the hand with the object axis around which the grasp will be made (Jeannerod, 1981; Jeannerod, Paulignan, Mackenzie, & Marteniuk, 1992). Imagine the rotation needed to grasp, with the right hand, an upright bottle directly in front of one. From a starting-point with the thumb in the 11 o’clock position (a natural resting state for the wrist: see Rosenbaum, Marchak, Barnes, Vaughan, Slotta, & Jorgensen, 1990) a clockwise rotation would be required. In order to grasp the same bottle laid horizontally, an anti-clockwise rotation would be used. The next experiment investigated the effect, on concurrent responses, of visual objects whose compatibility with wrist rotations, in the sense just described, was varied. The logic of Expt 2 was entirely analogous to that of Expt 1: participants indicated whether a tone was high or low by making a clockwise or anti-clockwise wrist rotation, whilst at the same time viewing an object. The expectation was that wrist rotation would be a further example of a micro-affordance and, in the circumstances of the
experiment, produce an interaction of object compatibility with response. Also, mapping effects and stimulus to stimulus compatibility effects were possible.

In addition Expt 2 aimed to examine the temporal properties of the compatibility effects. In Expt 1 and those reported in Tucker and Ellis (1998) the object producing action potentiation has been present in the participants’ visual field when making a response. Given the original theoretical motivation for the experiments, the compatibility effects would be predicted to be transient in that they arise from objects currently represented. The next experiment therefore also included a condition in which the response to the auditory signal was made immediately after the visual object was removed from view, rather than whilst it was present.

Method

Participants

All 64 participants were right-handed by self-report and had normal or corrected to normal vision. All were students at the University of Plymouth and received course credit or £2 for participating.

Apparatus and materials

The stimuli consisted of 40 objects, 20 tall cylindrical objects compatible with a clockwise wrist rotation and 20 either of small size or possessing horizontal grasp axes that were compatible with an anti-clockwise wrist rotation. The list of objects used is given in Table 2. A device was attached to the right wrist to monitor its resting position and measure responses. This consisted of two pairs of mercury switches. One pair was tuned such that a signal was sent whenever the wrist orientation strayed more than 3 degrees, in either direction, from the starting position. The other set responded to a rotation of 6 degrees or more. The stimuli were presented approximately 20 cm in front of the participants’ fingertips inside the one-way glass apparatus described in Expt 1. Participants sat with the base of their right forearms resting in a cylindrical arm rest that gave support whilst allowing the wrist freedom of rotational movement. Their arms were angled so that the hand was pointing toward the centre of the stimulus box. Feedback about the start position of the wrist was given by the small red light described in Expt 1. If participants’ wrists were outside the starting limits the red light would flash on and off rapidly. As the wrist approached the correct position the flashing would become less rapid and finally stop, with the light on continuously, when the correct start position was achieved. This position had to be maintained for 1 second for the trial to be initiated.

Procedure

The procedure was identical to that of Expt 1 except for the following variations. The response was a wrist rotation, rather than grip, with participants using only one mapping rule for the entire experiment (either high pitch—clockwise wrist rotation/low pitch—anti-clockwise wrist rotation or the reverse). Also there was an additional between-participants factor: the tone cueing the response was delivered either whilst the visual object remained in view (as in the previous experiment) or immediately after it was extinguished.

In summary a trial consisted of either: (1) the presentation of the (to-be-remembered) object for 700 milliseconds, after which a tone was delivered to which the participant responded with a wrist rotation, whilst the object remained in view, or (2) the presentation of the object for 700 milliseconds, its extinction, immediately followed by the tone, to which the participant responded with a wrist rotation.
Table 2. A list of the stimuli used in Expt 2

<table>
<thead>
<tr>
<th>Objects compatible with a clockwise wrist rotation</th>
<th></th>
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<tbody>
<tr>
<td>Brown bottle</td>
<td>Washing up bottle</td>
<td>Upright wooden block</td>
</tr>
<tr>
<td>Lemonade bottle</td>
<td>Aerosol can</td>
<td>Glass jar</td>
</tr>
<tr>
<td>Wine bottle</td>
<td>China bottle</td>
<td>Plastic tube</td>
</tr>
<tr>
<td>Squash bottle</td>
<td>Bleach bottle</td>
<td>Cardboard tube</td>
</tr>
<tr>
<td>Upright cardboard tube</td>
<td>Upright metal tube</td>
<td>Upright plastic tube</td>
</tr>
<tr>
<td>Plastic bottle</td>
<td>Aerosol can</td>
<td>Tall jar</td>
</tr>
<tr>
<td>Oil bottle</td>
<td>Glass coffee pot</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Objects compatible with an anti-clockwise wrist rotation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Small sponge</td>
<td>Table fork</td>
<td>Biro</td>
</tr>
<tr>
<td>Match box</td>
<td>Garden fork</td>
<td>Pen</td>
</tr>
<tr>
<td>Match box</td>
<td>Paint brush</td>
<td>Tooth brush</td>
</tr>
<tr>
<td>Cardboard box</td>
<td>Screw driver</td>
<td>Screw driver</td>
</tr>
<tr>
<td>Stapler</td>
<td>Scissors</td>
<td>Horizontal wooden block</td>
</tr>
<tr>
<td>Cardboard box</td>
<td>Pen</td>
<td></td>
</tr>
<tr>
<td>Stapler</td>
<td>Spoon</td>
<td>Pen</td>
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<tr>
<td>Plastic box</td>
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</table>

Results

Response times

Analysis by participants. The data from seven participants were excluded from analysis because their error rates exceeded 12.5%. One participant was also removed from the analyses for failing to recognize more than 2 out of the 12 seen objects in the recognition task even when these were presented for a much longer (100 milliseconds) duration at the end of the experiment. For the remainder condition means were calculated following the removal of response times more than two standard deviations from each participant’s overall average. An ANOVA of these data showed a main effect of object compatibility: responses executed in the presence of objects compatible with a clockwise wrist rotation produced faster reaction times than those compatible with an anti-clockwise rotation, (\(M = 388.0\) and \(393.0\) respectively), (\(F(1,52) = 4.02, p = .05\)). There was also a main effect of cue presentation. Those trials in which tone and object were simultaneously present produced faster responses than those in which the tone appeared immediately after the object was extinguished (\(M = 360.8, 420.3\) respectively); (\(F(1,52) = 7.56, p = .008\)).

Once again, however, the most important result was the significant interaction between object compatibility and response. In the presence of clockwise compatible objects, clockwise responses were executed faster (\(M = 382.9\)) than anti-clockwise responses (\(M = 393.1\)), whereas in the presence of anti-clockwise compatible objects, the clockwise responses (\(M = 393.3\)) and anti-clockwise responses (\(M = 393.0\)) hardly differed (\(F(1,52) = 6.75, p = .012\)). This effect is illustrated in Fig. 5.

The three-way interaction between object compatibility, response and mapping was also significant (\(F(1,52) = 5.28, p = .026\)) and, as can be seen in Fig. 6, indicates that the object compatibility by response effect was confined to the low
tone/clockwise response mapping. Analysis of the simple interaction effects broken down by mapping showed that the response by object compatibility effect for the clockwise to low tone mapping was significant ($F(1,26) = 8.75, p = .007$) whereas for the clockwise to high tone mapping the interaction did not approach significance ($F(1,26) = .07, p = .791$).

The three-way interaction of time of visual object presentation by object compatibility by response was not significant ($F(1,52) = .07, p = .791$). Not having the visual object in view appears not to have affected the object compatibility by response effect.

**Analysis by materials.** Analysis of the data with objects as a random factor indicated, as did the analysis by participants, a main effect of cue presentation time ($F(1,38) = 314.4, p < .0001$). In contrast, there was no main effect of object compatibility, but that of response was significant ($F(1,38) = 4.71, p = .036$). Also there was a highly significant effect of response mapping ($F(1,38) = 218.8, p < .0001$), which is best interpreted in the context of the significant interaction of response mapping by cue presentation time ($F(1,38) = 186.5, p < .0001$). The latter may be understood as a 59 milliseconds speed advantage for the high tone/clockwise mapping when the tone was delivered immediately after the object was extinguished, whilst no such benefit was observed when the object and tone were presented together.

The pattern of data for the cases of prime theoretical interest were broadly similar to those obtained with the analysis by subjects. That is, there was a significant interaction of response by object compatibility ($F(1,38) = 6.99, p = .012$), and significant three-way interaction between this and response mapping ($F(1,38) = 6.74, p = .013$).

The statistic $F_{min}$ was not significant for the response by object compatibility interaction ($F_{min} = 3.43, F_{min}(.05, 1, 61) = 4.00$).

**Error rates**

These data were subjected to a mixed ANOVA, indicating just two significant effects. A two-way interaction of response by mapping ($F(1,52) = 4.76, p = .034$) consisted of fewer errors in the clockwise high than in the anti-clockwise high mapping when making a clockwise response ($M = 5.3, 6.6$ respectively); whilst the pattern was
reversed for the anti-clockwise responses ($M = 7.2, 5.6$ respectively). This is perhaps best understood as an effect of tone: the two lowest error scores being associated with high tones, and the two highest with low tones.

There was also a three-way interaction of object compatibility by mapping by time of visual object presentation. When the tone and object were simultaneously present the clockwise to high tone mapping produced fewer errors in the presence of clockwise compatible objects than with anti-clockwise compatible ones ($M = 5.3, 7.0$ respectively). With the converse mapping slightly more errors were made in the presence of clockwise compatible objects than with anti-clockwise compatible ones ($M = 7.1, 6.9$ respectively). When the tone was delivered immediately after the extinction of the object the pattern of error data was essentially the mirror image of this. That is, the clockwise to high tone mapping produced more errors when paired with clockwise compatible objects compared to anti-clockwise compatible ones ($M = 7.1, 5.8$ respectively). In the case of the anti-clockwise to high tone mapping fewer errors were made with clockwise compatible objects compared to the anti-clockwise compatible cases ($M = 4.6, 5.7$ respectively). The pattern of data suggests that the relative ease of the mappings was effected (for reasons unknown) by whether a visual object was present during response execution, but this effect was confined to the clockwise compatible objects. The latter were in general larger, than the anti-clockwise compatible objects, and therefore perhaps more difficult to ignore when responding to the tone. The presence or absence of the clockwise compatible objects would have effected the ease of mapping, whereas the presence or absence of the anti-clockwise objects would not.

These accounts of the error effects are entirely speculative, but neither has an impact on the important aspects of the response latency data. That is, there was no evidence for a speed–error trade off in the case of the response by compatibility interaction.

**Discussion**

Once again a visual stimulus to response compatibility effect was obtained. As in the previous experiment participants were merely observing an object, and not required
to make any response in relation to it at the time of presentation. Even so, in one of the mappings, objects effected a component of a concurrent action and this observation constitutes a demonstration of micro-affordances of wrist rotation.

The object compatibility by response interaction was confined to the low/clockwise to high/anti-clockwise mapping (Fig. 6). A similar effect of mapping in Expt 1 led us to entertain two possibilities. One is that the affordance is subject to passive decay that begins at the point of stimulus presentation, and difficult mappings, producing the slowest response latencies, will ‘conceal’ the action potentiation effect. This account is undermined by the data of Expt 2 in which the compatibility effect was observed in the mapping that was the slowest.

The second account of why the compatibility effect was confined to one tone to response mapping was concerned with stimulus to stimulus compatibility. This is our preferred account. Certainly similar stimulus to stimulus associations were possible in the second experiment, where, in general, the clockwise compatible objects are larger than the anti-clockwise compatible ones. In the clockwise-low/anti-clockwise-high mapping therefore any stimulus to stimulus congruence between the tones and the objects would have been preserved in the compatible trials, whereas in the converse mappings it would not be. Moreover this stimulus to stimulus compatibility account of these aspects of the data is supported by results reported elsewhere (Tucker & Ellis, 2000). A precision/power grip compatibility effect was observed when subjects simply classified real objects, briefly presented, as organic or manufactured. In these circumstances, with no possibility of stimulus to stimulus compatibility, the effect was obtained in both mappings of response categories (precision/power) to object categories (manufactured/organic). This finding therefore confirms the generality of the micro-affordance of grip type and is consistent with our account of the compatibility by mapping interaction in Expt 1.

The absence of an interaction between the compatibility effect and the time of presentation of the visual object implies that the compatibility effect did not depend on the object being in view at the time of response. However, there are reasons to doubt such an inference. There is a (statistically non-significant) trend in the data indicating a reduced compatibility effect when the visual object was not present. It remains possible, therefore, that the activation is transient, in accord with current thinking about visual processing in the dorsal pathway. It has been argued that visual-motor activation in this processing stream is of necessity highly transient and constantly updated, so as to meet the demands of on-line control of changes in objects of interest, goal states and motor states (Goodale, 1993; Goodale & Servos, 1992). Moreover Tucker and Ellis (2000) report that the micro-affordance of grip type is present when an object is in view, reduced, but still present, immediately after extinction of the object and eliminated 300 milliseconds after extinction.

Three types of compatibility effects may be inferred from these experiments. Two of these, the mapping and stimulus to stimulus effects, are of secondary interest. The third, the visual object compatibility effects on responses, are the prime focus of this paper and their theoretical implications are described below.
GENERAL DISCUSSION

These two experiments confirm and extend the previously reported evidence for action potentiation by seen objects (Tucker & Ellis, 1998). Seen objects appear to facilitate components of actions which are irrelevant to the current behavioural goals of the view.\(^3\) The effects are small, as they must be if they are not to disrupt current, goal-directed actions. They are highly consistent, however, as their observation with a variety of different classes of action over a variety of different experimental contexts confirms.

Like the effects of object orientation on hand of response reported in Tucker and Ellis (1998), these new data demonstrate the extraction of action-related properties from a range of disparate visual properties. It is not the case that a single feature of each object is paired with a particular action. For example, in the case of the direction of wrist rotation, the orientation of the axis of elongation or the size of an object determined which was the compatible direction of rotation. Just as with orientation, it is unlikely that there is a fixed perceptual property that can account for the derivation of a relevant code. It should be noted that this fact alone places these effects beyond the normal range of SRC effects, in which some fixed, usually visual, property is assumed to give rise to an abstract stimulus code. For example, the position in visual space specifies ‘left’ or ‘right’.

The new data have a number of theoretical implications. First, two further components of action, which are open to potentiation, have been identified: wrist rotation and type of grasp. Section 1 below discusses the theoretical implications of this observation in relation to the notion of micro-affordance. Secondly, the results are clearly relevant to existing theories of various SRC effects, these are discussed in section 2 on stimulus–response compatibility below. Thirdly, aspects of the data fit a particular model of visual-motor representation, which is sketched in section 3 below.

1. **Micro-affordance**

The notion of affordance was, of course, originally coined by Gibson (1979). In his view aspects of the visual world furnish the viewer with possible actions. Surfaces may be stand-on-able or sit-on-able. A given object may afford a whole range of behavioural possibilities: it may be thrown, grasped, pressed, pressed, eaten and kicked. These behavioural possibilities are, in the Gibsonian tradition, in the object in the sense that they are fully specified by the pattern of stimulation the object provides to a viewer. In contrast to this notion of affordances being dispositional properties of objects and events, our notion has them as dispositional properties of a viewer’s nervous system. We make clear in section 3 below that the dispositions arise as a result of adaptation of the nervous system over both evolutionary time scales and the lifetime of an individual.

\(^3\) It is true that an aspect of the object is relevant to a viewer’s current behaviour. He/she is after all making compatible/incompatible responses. Our point is that a viewer is being affected by grasp-related properties of an object, which he/she has no intention of grasping.
A second difference between Gibsonian affordance and the alternative developed here is to do with the level of specification. The facilitated actions observed in our experiments are of specific components of grasping. Moreover they involve facilitation of particular values of the components concerned. It is not grasping in general that is facilitated, but a specific grasp appropriate to the viewed object. It is a particular shape of the hand and a particular orientation of the wrist, which are afforded. We term these effects, for obvious reasons, micro-affordances.

The relationship between micro-affordance and seemingly higher level effects, similar in nature, remains to be clarified. Neuropsychological dissociations, for instance, have been observed between patients’ ability to name a seen object and their ability to gesture an appropriate action for the same object. It is of particular interest that the actions are not always of a very general kind, such as those that might be produced by a normal subject when asked to mime the use of an imaginary object. Riddoch and Humphreys (1987) describe a patient, whose naming of common objects was impaired, yet correctly gestured the use of knives and forks, including the use of the appropriate hand. His semantic knowledge of seen objects was shown to be poor, leading to the authors’ claim that the accurate gesturing resulted from a so-called direct route from vision to action. In contrast Sirigu et al. (1995) describe a patient impaired in all aspects of gestural behaviour of this sort, whilst recognition was preserved.

Rumita and Humphreys (1998) described effects that may also be interpreted as indicating a direct route to action. In their experiments normal participants were required to either name or to gesture the use of pictured objects. Significant numbers of errors were ensured by having the response subject to a deadline, and the errors were classified. The higher proportion of visual errors, such as confusing a screwdriver with a knife, when gesturing compared to when naming was accounted for in terms of partial activation of competing response options available via the direct route from vision to action.

Do the gestures made to seen objects, in these studies, consist of sets of micro-affordances? That is, is a gesture accurate in the sense of its components being optimal for the actual use of the seen object, or is it merely a mime of the typical behavioural possibilities afforded by the object? A finer-grained analysis than is currently available, of the actual gesturing, is required to answer this question.

2. **Stimulus–response compatibility**

The stimuli used in the SRC paradigm are often abstract, and therefore not associated with a set of real-world actions. There is nothing that a coloured letter affords, in the sense of affordance used here. The compatibility effects are therefore assumed to be between aspects of the abstract stimulus and the arbitrary response options, set by the experimenter. Accordingly some theories of SRC effects refer to the abstract cognitive codes elicited by the stimuli and response options. It is assumed that the presentation of a stimulus gives rise to mental codes of its various properties, such as colour, form and spatial location; whilst abstract motor codes are generated by the
task demands. In the case of bimanual responses the location of the effector, left or right, would be coded in this way. Whenever the two sets of codes overlap there is the potential for an SRC effect (Kornblum, 1994; Kornblum & Lee, 1995; Kornblum, Hasbroucq, & Osman, 1990).

Given the notion of micro- affordance, however, other possibilities arise. Components of abstract visual objects may evoke micro- affordances, without affording any particular coherent action. The spatial location of an object, in particular, might be expected to give rise to micro- affordances which may interact with explicit responses to that object, to produce outcomes such as the spatial Simon effects. As has been argued previously (Tucker & Ellis, 1998) this possibility does not preclude the role of more abstract codes of the sort proposed by dimensional overlap accounts of SRC effects. This is self-evidently the case where spatial compatibility effects are obtained even when the response is verbal (Weeks & Proctor, 1990). The proposal here is for multiple response codes (see Lamberts, Tavernier, & d’Ydeuwalle, 1992, for evidence of the existence of multiple spatial codes within an SRC paradigm), some of which may be correctly classed as micro- affordances. Two virtues are associated with this position. First, it goes some way towards explaining why response codes are automatically generated and gives a non-arbitrary basis for their properties. Secondly, it provides a way of generalizing the notion of stimulus- response compatibility to those cases which do involve a meaningful, non-arbitrary relationship between responses and a stimulus, which the standard SRC accounts clearly do not.

Some SRC theorists have proposed models related to the micro- affordance account. Michaels (1988, 1993) has described an essentially Gibsonian framework for understanding SRC effects. She argues that some of the benefits of compatible mappings depend not on arbitrary pairings between mental codes for aspects of a stimulus and responses, but on ecological relations between visual properties and action. This approach explicitly rejects the notion of mental representation. In contrast Hommel (1997) has developed the notion of action effect codes, which form the basis of intentional actions. The effect code is a representation of the sensory effects of a voluntary action, and becomes associated with the motor pattern producing the effects and so forms the basis of voluntary actions. An actor can produce an intended effect by choosing an appropriate effects code, which in turn selects the appropriate motor pattern. On this account compatibility effects occur because stimulus codes may overlap with effect codes, leading to response competition in some cases.

These two views and the micro- affordance approach sketched in this paper share the assumption that at least some compatibility effects arise from relations between visual objects and possible, real-world actions that can be performed on them. All three approaches also deliberately blur the distinction between perception and action. The micro- affordance account diverges from the ecological in retaining the notion of representation, and from the action effect account in having direct associations between vision and action. It differs from both in claiming that these associations give rise to action potentiation whenever an object is seen, whatever the intentions of the viewer. The next section sketches a theory of brain development which may account for these intimate associations.
3. Development, visual representation and action

Edelman (1978, 1987) described a theory of brain development that adopts a neural form of Darwinism and that makes biological sense of micro-affordance. An individual brain, according to the theory, is shaped, during prenatal and postnatal development, by pressures similar to natural selection. The development of adaptive behaviour requires the integration of sensory and motor processes. It is proposed that learning coordinated actions, such as reaching and grasping, results from the gradual adaptation of the neuronal groups so that those involved in a successful action, such as one leading to contact with an object, become selected for that purpose (Sporns & Edelman, 1993). This process leads to the coupling of motor and sensory systems within a so-called global neural mapping. Such mappings are said to not only underpin adaptive behaviour, but form the basis of categorization of external objects and events. We speculate that the micro-affordances observed in the experiments reported here reflect the involvement of the motor components of the global mappings, which have come, during development, to represent visual objects.

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References


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