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Action priming by briefly presented objects

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Abstract

Three experiments investigated how visual objects prime the actions they afford. The principal concern was whether such visuomotor priming depends upon a concurrent visual input—as would be expected if it is mediated by on-line dorsal system processes. Experiment 1 showed there to be essentially identical advantages for making afforded over non-afforded responses when these were made to objects still in view and following brief (30 or 50 ms) object exposures that were backward masked. Experiment 2 showed that affordance effects were also unaffected by stimulus degradation. Finally, Experiment 3 showed there to be statistically equal effects from images of objects and their names. The results suggest that an active object representation is sufficient to generate affordance compatibility effects based on associated actions, whether or not the object is concurrently visible.

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1. Introduction

How do objects come to activate the patterns of motor activity associated with their affordances? In this paper we aim to clarify the results of earlier experiments showing the activation of affordances from visual objects. In particular we wanted to examine the requirement that an on-line visual object needs to be present in order to activate motor patterns associated with the object affordances.

There is a growing body of evidence that the observation of an object merely to categorise it, or comprehend it, is sufficient to partially activate motoric representations (Chao & Martin, 2000; Gerlach et al., 2002; Grafton et al., 1997; Grèzes &

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Decety, 2002; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003; Martin, Wiggs, Ungerleider, & Haxby, 1996). Assuming that this activation, in motor and motor related areas of the brain, relates to the actions associated with the object, one would expect to be able to observe behavioural effects on actions. (This assumes, in addition, that this motor and visuomotor activity involves the same, or similar, neural systems to those involved in planning and executing a real action—a plausible assumption given, for instance, the evidence for the similarity between the brain systems underlying both vision and visual imagery (Kosslyn, 1994) and action and motor imagery (Jeannerod, 1994).) There is increasing evidence for just such effects: The execution of an action whilst viewing a manipulable object is affected by the congruency of the action to the object (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Ellis & Tucker, 2000; Klatzky, Fikes, & Pellegrino, 1995; Riddoch, Edwards, Humphreys, West, & Heafield, 1998; Tucker & Ellis, 1998, 2001). If one also includes the relations between object location and effector position amongst this evidence, it is considerably broadened by the extensive literature on the Simon effect (for a review see Hommel, 1995; Kornblum, Hasbroucq, & Osman, 1990).

The state of the motor system also affects the visual system. Preparing to grasp an object results in enhanced processing of similarly shaped and oriented objects (Craighero et al., 1999). The classic mental rotation task (Shepard & Meltzer, 1971) is also executed faster and more accurately when people concurrently perform a manual rotation in the same direction as the required 'mental' rotation (Wexler, Kosslyn, & Berthoz, 1998).

The premotor cortex and related areas become activated when we look at manipulable objects and this activity itself is part of a reciprocal system that in turn influences the way we attend to, and parse, objects in a scene (see e.g. Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003). Under exactly what conditions, and by what routes, this kind of motor area activity (that might contribute to the representation of object affordances) becomes active is undetermined at present. We have previously suggested that the automatic and dedicated nature of the visuomotor networks within the dorsal stream (Milner & Goodale, 1993) would make this a good candidate for generating affordance-based representations within the motor and visuomotor areas (Tucker & Ellis, 1998, 2001). Thus even when an object is not, or is not yet, a target for action, attending to it could partially activate motor representations appropriate to reaching, grasping and manipulating it. It is partly the *automatic* nature of these transformations that make this system suitable for such a role. For example, spatial perturbations during reaching automatically result in on-line trajectory changes to the new target position even when participants are required to abort a reach when such perturbations occur (Pisella et al., 2000). In contrast the same authors found that target perturbations defined by a colour change did not invoke this automatic tendency to rapidly adjust and carry on a reaching movement.

The dorsal system has been framed as a network dedicated to transforming visual information into motor output with minimal influence from other (e.g. ventral) systems (Goodale & Milner, 1992; Milner & Goodale, 1993). Goodale and Humphrey (1998) suggest that one of the roles of the ventral system is to direct the dorsal system to a suitable target. Once so directed, the target object's parameters will be trans-

formed into motor output automatically, and with minimal influence from the ventral system. Their theory does not deny ventral influence but assigns it essentially a ‘steering’ role. Functional knowledge about the appropriate part of a tool to grasp, for instance, could be used merely to direct the dorsal system to that part of the object. Indeed, where knowledge *is* required to direct the dorsal system to an appropriate object part then concurrent tasks which tax the semantic system also disrupt the accurate steering of the dorsal system (see Creem & Proffitt, 2001). This naturally leads to the question of how much long-term object–action knowledge contributes to the generation of affordances, and whether the motor patterns underlying this knowledge can be activated without the need for any ‘on-line’ dorsal processing of a currently visible object. The particular specialisation of the dorsal system is the on-line control of an unfolding action (see Glover (in press) for a recent review based on the control–planning distinction and its relation to the dorsal–ventral systems). The monitoring of object properties to direct an action needs to be computed quickly and very precisely—not broad ‘categories of action’ but detailed and constantly updated spatio-temporal instructions to, for example, guide the fingers and thumb to appropriate locations on an object’s surface. Necessarily, viewpoint dependent object properties such as location and orientation must be computed on-line as this information is subject to continuous variation as we (or the target) move. This is not to say, however, that we do not retain any spatial information off-line. We can reach for and navigate around objects based on memory (albeit relatively poorly and cautiously). In fact, spatial information that is temporarily bound to an object has been shown to exert correspondence effects on manual responses. Hommel (2002) showed that reactivating a single target from a multi-object display—by cueing its colour up to several seconds after the display had been masked—yielded reliable spatial compatibility effects (see also Tlauka & McKenna, 1998).

More intrinsic properties, such as actual object size, are more complex. Whilst the proximal stimulus varies with distance the actual stimulus does not—allowing it to meaningfully be associated with the object together with higher level functional knowledge. Thus we know that a grape is small and requires a particular kind of grasp (including preserved visuomotor knowledge about the force requirements, Flanagan et al., 2001). Whilst the precise guidance of the thumb and index finger during prehension will rely more and more on the specialised control circuits within the dorsal stream (Glover, in press), our knowledge of the object allows information about the *type* of grasp to be available before precise parameterisation takes place.

For a property such as object size there are thus at least two routes to the activation of its affordance for a particular grasp: an on-line route—relying on immediate visual input and based on the physical stimulus size—with little influence of higher level knowledge (although the two will naturally covary), and a ‘knowledge route’ based on the semantics of the object and the history of past interactions. Within the latter category further subdivision is possible. For example Humphreys and colleagues (Phillips, Humphreys, Noppeney, & Price, 2002; Riddoch, Humphreys, & Price, 1989; Rumiati & Humphreys, 1998) have developed a theory of routes to action that incorporates both direct vision-to-action and mediated vision-to-semantics-to-action routes. For instance Rumiati and Humphreys (1998) showed that under

time-pressured conditions subjects were more likely to make miming errors based on the visual attributes of an object (i.e. via the direct vision-to-action route) when cued by pictures, but to make errors based on the semantic associates of the object when miming to words. Neither the direct or indirect route in this model is based on the kind of fast and automatic processing within the dorsal system. The direct route here involves a direct linkage between stored associations of visual attributes and particular actions (including high level actions dependent upon knowledge of object function). Patients with ideomotor ataxia also reveal specific deficits in the long-term component of object action knowledge. They are, for example, better at producing appropriate hand shapes to novel objects (as these rely only upon dorsal or 'on-line' information about shape) than to familiar objects where functional use has been able to modify the style of manipulation away from that which would be derived from their physical properties alone (Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; see also Sirigu et al., 1995).

In a previous study of affordances Tucker and Ellis (2001) employed a Go–NoGo paradigm to examine the time-course of grasp compatibility effects to pictures of objects that would normally be grasped either with precision or whole-hand grips. We found that affordance-based compatibility effects tended to become larger the longer the visual object was present and to rapidly diminish once it disappeared. The rapid disappearance, following object offset, is consistent with the 'on-line' or dorsal route for affordance extraction, as this would rely on on-line computations that are transient and rapidly updated. Terminating the visual object also terminates the visuo-motor transformations responsible for activating the compatible or incompatible motor response. We therefore concluded that it was most likely the on-line dorsal system that was responsible for the compatibility effects obtained. A recent fMRI study of the same paradigm showed a correlation between the size of the compatibility effect across subjects and the amount of activation in a left parietal network that included the dorsal premotor cortex (Grèzes et al., 2003). Such activation is consistent with but does not imply that it arose via the on-line dorsal route.

The current experiments attempted to re-examine grasp affordance effects under time-course conditions that would enable or disable the availability of an on-line visual object during response selection and execution. A critical feature of the previous experiments was the fact that response selection was not cued by the visual objects (whose category determined whether the trial was a Go or NoGo trial) but by a high or low pitched tone. When the tone onset triggered the offset of the visual object any grasp affordance effects were dramatically reduced, and they were completely abolished when the tone occurred after the visual object had already been offset. Whilst we interpreted this rapid decay as broadly consistent with the motor patterns being activated via the dorsal route they could not rule out alternative explanations.

2. Experiment 1

Our previous observations of the grasp compatibility effect were obtained with a minimum stimulus exposure time of 300 ms. In the current experiment precision and

whole-hand grasp responses were elicited to objects exposed within the 20–300 ms range with and without backward masking by a low spatial frequency noise stimulus. A previous pilot experiment found evidence for grasp compatibility effects after brief (20–80 ms) masked stimulus presentations. Under such conditions the target object would not be visible when the response was selected and executed. This provided some preliminary evidence against the necessity for visual objects to be visible during response selection in order to produce grasp compatibility effects. The purpose of Experiment 1 was to confirm that the concurrent visual presence of a graspable object was not required in order to generate affordance compatibility.

2.1. Method

2.1.1. Design and materials

The stimulus set was made of black and white digital photographs (800×600 pixels) of 16 common objects. Eight of the objects were natural (fruit, vegetables, or nuts) and half were man-made (tools or utensils). Within each category, four objects required precision grasps (simply referred to as Small Objects to avoid confusion with the response terms) and four power grasps (Large Objects). The objects are listed in Appendix A. Each object was photographed in a single rightward orientation resulting in 16 individual pictures whose on-screen size was approximately 10% smaller than their actual size. Each slide was presented four times at each of the five durations—20, 30, 50, 150 and 300 ms with and without backward masking—resulting in a total of 640 trials.

2.1.2. Procedure

Participants sat in front of the computer monitor (a 19 in. Mitsubishi Diamond-tron @ 100 Hz), with their eyes about 35 cm away and their hands resting on the table. In their dominant hand they operated the response device. Their middle, ring and little fingers enclosed a cylinder, 11 cm tall and 1.8 cm in diameter, that could be squeezed to trigger a response. Their index finger and thumb held a thin tactile-feed-back switch. The two responses mimicked a Power and Precision grip respectively (the device is illustrated in Tucker & Ellis, 2001).

A blank grey screen signalled the start of each trial. Five hundred milliseconds later the target object appeared. After the variable duration the target was replaced either by one of four randomly selected noise masks or by a photograph of the empty background. Participants had to indicate whether they thought the object was natural or manufactured by making a response on the hand device. Half the participants depressed the switch between the index finger and thumb for natural objects and that between the palm and middle, ring, and little fingers for manufactured objects. The remainder of the participants used the opposite mapping rule. Fig. 1 shows a schematic of the trial types.

The stimuli remained in view for 3 s or until a response was made, after which a blank grey screen appeared that was slightly darker than the start screen (allowing the luminance increase of the next trial's start screen to act as a preparatory signal). Participants each received 20 practice trials at the start of the experiment and were

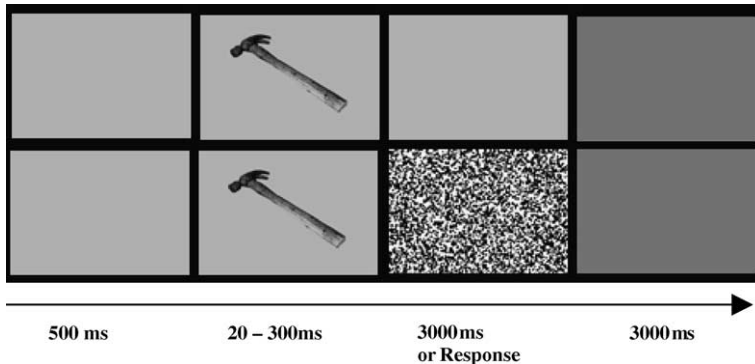


Fig. 1. Example unmasked and masked trial sequences in Experiment 1. For timing details see text.

asked to respond as fast and accurately as they could. The experiment consisted of two identical blocks of 320 trials with the presentation order completely randomised within each block.

2.1.3. Participants

Thirty six students from the University of Plymouth took part in the experiment. All had normal or corrected to normal vision and were paid £4.00 or received course credits for their time. Four participants, whose error rates exceeded 10%, were excluded from the analysis.

2.2. Results

Reaction times more than 2 standard deviations¹ from each participant's condition means were excluded from this analysis and the analyses of all other experiments reported. Correct RTs and percentage error rates were entered into a mixed ANOVA: Object Size (Small or Large) × Response (Precision or Power) × Stimulus Duration (20, 30, 50, 150, 300 ms) × Masking (Masked, Unmasked) and the between participant factor Mapping (Natural = Precision Response or Natural = Power Response). The larger, power grip compatible objects, produced responses that were, on average, 32 ms faster, $F(1, 30) = 57.5$, $p < 0.001$, $MSe = 5753.2$, and made with 6% fewer errors, $F(1, 30) = 122.9$, $p < 0.001$, $MSe = 101.4$, than the smaller objects. Both the masking and stimulus exposure time manipulations produced significant and predictable effects. Overall unmasked stimuli were responded to faster ($M = 548.6$ vs. 606.0; $F(1, 30) = 54.0$, $p < 0.001$, $MSe = 19456.5$) and more accurately ($M = 10\%$ vs. 22%; $F(1, 30) = 288.8$, $p < 0.001$, $MSe = 163.8$) than masked stimuli. The effect of duration, $F(1.2, 36.3) = 26.4$, $p < 0.001$, $MSe = 43097$ (RT),

¹ Standard deviations for each participant were based on a weighted average of their condition SDs. This outlier criterion typically removes about 4% of the data.

² In all analyses this superscript indicates the use of Greenhouse–Geiser adjustments to the degrees of freedom for effect tests where sphericity cannot be assumed.

and, $F(2.8, 85.2)^{\text{§}} = 150.9$, $p < 0.001$, $MSe = 193.6$ (%E), indicated that speed and accuracy improved as stimulus exposure time increased (see Fig. 2). There was a main effect of Response that was restricted to the error data, $F(1, 30) = 5.1$, $p < 0.05$, $MSe = 140.5$. Power grip responses ($M = 15.4\%$) were made slightly more accurately than Precision grip responses ($M = 16.9\%$).

As is apparent from Fig. 2, the impact of the mask depended on stimulus duration, $F(1.2, 36.3)^{\text{§}} = 20.3$, $p < 0.001$, $MSe = 33590.7$ (RT), and, $F(3.1, 93.4)^{\text{§}} = 128.6$, $p < 0.001$, $MSe = 130.6$ (%E). The performance cost of masked trials increased as stimulus duration decreased. This was true for both reaction time and error rates although most marked for the latter. Stimulus duration affected response accuracy to large and small objects differently, $F(4, 120) = 12.7$, $p < 0.001$, $MSe = 65.5$. For both power and precision compatible objects the error rates levelled out at around 10% as the stimulus duration increased. However the small precision compatible objects began with an error rate approximately 10% higher at the shortest duration and only reached a baseline at the 150 ms duration (see Fig. 3).

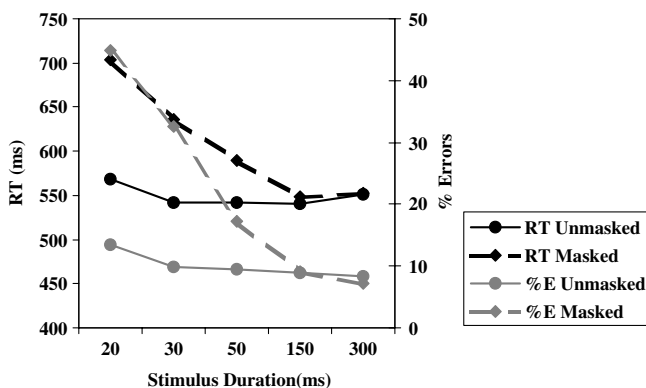


Fig. 2. Reaction times and %error rates for Experiment 1 by Stimulus Duration and Masking.

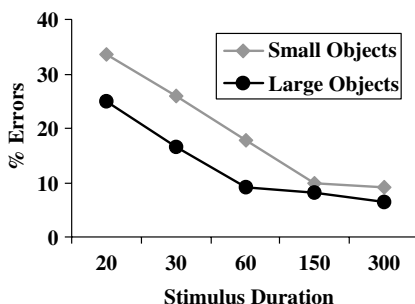


Fig. 3. %Error rates for Large and Small objects by Stimulus Duration from Experiment 1.

The Object Size by Response compatibility effect was significant in both RT, $F(1, 30) = 20.2$, $MSe = 5465$, $p < 0.001$, and error rates, $F(1, 30) = 24.7$, $p < 0.001$, $MSe = 127.8$, and interacted with the masking manipulation in the RT data, $F(1, 30) = 7.6$, $p = 0.01$, $MSe = 1545.9$, but not quite significantly in the error data—although a similar pattern was observed. Whilst the pattern remained similar the compatibility effect was more distinct when the stimuli were unmasked (see Fig. 4).

There was no evidence that stimulus duration affected the magnitude of the compatibility effect in RT but it did so in the error data, $F(4, 120) = 3.18$, $p = 0.016$, $MSe = 85.3$. This effect can be seen in the Error graph of Fig. 5 (the Masking factor is also included for comparison with the RT data). Here the Response by Object Size factor has been collapsed to form the single factor Compatibility—Power responses to large objects and precision responses to small objects counted as compatible trials whilst both non-matching stimulus response pairings made up the incompatible trials. The four-way interaction between Object Size, Response, Duration and Masking was significant in the RT data, $F(2.6, 79.9)^{\text{§}} = 3.9$, $p = 0.015$, $MSe = 5791.2$. This is

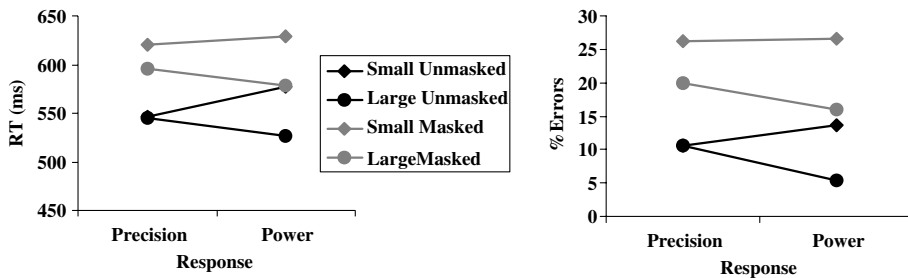


Fig. 4. The Response by Object Size compatibility effect from Experiment 1 for both masked and unmasked stimuli.

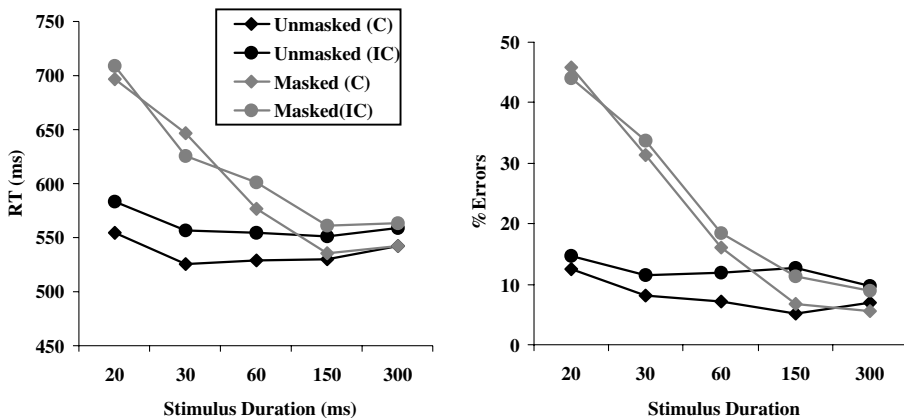


Fig. 5. The Response by Object Size compatibility effect (collapsed as the single factor Compatibility) by stimulus duration and masking for Experiment 1. C = Compatible, IC = incompatible.

displayed in the RT section of Fig. 5 with the Size by Response interaction collapsed to the statistically equivalent single factor Compatibility. As Fig. 5 shows, the effect of masking was to selectively disrupt the (Response by Size) compatibility effect during the short exposure times. As we also observed in our pilot experiment, there was a trend towards an *incompatibility* effect with short masked exposures although this was not statistically reliable and should be treated with caution given the high error rates associated with the very brief masked stimulus exposures.

2.3. Discussion

The Object Size by Response compatibility effect occurs with very brief stimulus exposure times even when these have been backward masked. There was also a suggestion of negative compatibility at the briefest duration but this was not statistically significant. Nonetheless this trend is similar to those reported by Eimer and Schlaghecken (1998) (Schlaghecken & Eimer, 1997) showing evidence for negative S–R compatibility for briefly presented arrow prime stimuli. It is possible that the set-up used in this experiment also induced a similar effect, whereby an initially activated response is then suppressed for want of current visual information to warrant its continued activation. That an indication of negative compatibility was only found for masked trials is also in accordance with other studies showing that masking is critical for negative compatibility effects (e.g. Klapp & Hinkley, 2002).

The most significant result, however, was the fact that briefly presented masked and unmasked objects induced affordance compatibility effects despite not being visible at the time the response was selected, prepared and executed. This does not support the requirement that the object needs to be visible during response selection. Overall, the compatibility effect is slightly more marked without masking but this difference presumably arises because masking effectively disrupts *identification* at the shorter stimulus exposures. As long as the target object has been visible for long enough before the mask to enable subsequent identification, the compatibility effects produced are essentially the same as when the object remains in view. This is most evident from the unmasked short exposure trials (see Fig. 5). Even at exposure times well below 100 ms, when response selection would rely on the maintenance of the target in short-term memory, the compatibility effect is as large as that obtained for exposures of 150 ms and above. This finding initially seems to be at odds with the results that we reported using a Go–NoGo paradigm (Tucker & Ellis, 2001). In the latter study grasp compatibility effects were found to rapidly extinguish following object offset. However the two results are not as comparable as they first appear. In contrast to the Tucker and Ellis (2001) paradigm, the present experiment, at least for the short stimulus exposure times, required participants to maintain object information after the object disappeared, in order to select a response. In the Go–NoGo paradigm when the response cue triggered the offset of the object, or came after the object, there was no need to maintain the object in memory—there would have been sufficient time to translate the visual object into a readiness to respond or withhold responding. The data do, however, force a modification of our conclusions from the Go–NoGo study concerning the process responsible for the generation

affordance-based motor priming. The presence of an activated motor response would not seem to depend on the concurrent presence of a visual object. The maintenance of a representation of the object in short-term memory seems to be sufficient to induce the effect (a result similar to the object location effects observed by Hommel (2002)). This implies that the activation of a compatible motor response does not necessarily rely on the transient on-line processing associated with the so called ‘action stream’ in the dorsal pathway. Instead it would appear that longer-term object–action associations can induce the effect.

In contrast to what we found from RT bin analyses in Tucker and Ellis (2001), there is little evidence here that the effect becomes larger with increasing exposure time. For unmasked stimuli such a trend is completely absent in reaction times. For masked stimuli the pattern suggests the gradual increase in the effect—but this is most readily explained as an indirect effect of stimulus duration. With masked trials performance is increasingly affected by shorter durations and it is this decrease in overall performance, rather than any direct effect of duration per se, that most obviously accounts for the trend.

3. Experiment 2

The data from Experiment 1 provide no reason to suppose that the on-line presence of a visual object alters the pattern or magnitude of grasp based compatibility. In this experiment we included two further manipulations within the visible (i.e. long-term presentation) condition. The procedure was similar to the previous experiments. There were four presentation conditions—a brief exposure condition where the stimuli were presented for 50 ms but without masking (50), a long-term presentation condition where stimuli remained in view until a response was made or 2500 ms had elapsed (2500), a degraded condition where the stimuli were reduced in contrast by 90% (Deg.), and an occluded condition where they were presented behind a grid (Occ.). In both latter conditions the object remained in view until a response was made or 2500 ms had elapsed.

The rationale was as follows: Experiment 1 suggested that the on-line presence of a visual object is not necessary to prime a particular type of grasp. Moreover, very short-term ‘iconic’ visual memory for the objects is also unlikely to be necessary because masking (which effectively disrupts performance) only affects the affordance when it also prevents identification. If the activation of the object affordance is dependent only on identifying the object, then manipulations of the visual context within which the object is displayed should have little impact. Placing the object behind a grid, which gives a context specifying that the object cannot be reached for, would be unlikely to change the effect. The contrast-reduced condition was added to evaluate the effect of increasing the normal separation between the time that overall size information and object identity would be available. Although the presence of the effect, even when visual objects are no longer visible, decreases the probability that this manipulation would be important, we thought it necessary given the temporal nature of irrelevant codes within stimulus–response compatibility paradigms (e.g.

Hommel, 1994). If the compatibility effect arises, in part, from a match between object size codes and size codes based on the responses then making size information available earlier, relative to identity information, should reduce the effect as the irrelevant size code will have had time to decay.

3.1. Method

3.1.1. Apparatus and design

This was the same as the previous experiment except that the conditions were as described above.

3.1.2. Participants

Thirty students from the University of Plymouth took part. All had normal or corrected to normal vision and were paid £4.00 or received course credits for their time.

3.2. Results

Correct RTs and error rates were entered into a mixed ANOVA with the within participants factors Object Size (Small, Large), Response (Precision, Power), Condition (50, 2500, Deg., Occ.) and the between participants factor Mapping (Natural = Precision Response or Natural = Power Response). Object Size produced similar effects to the previous experiment. Participants responded to the larger power compatible objects ($M = 601$) approximately 33 ms faster than the smaller precision compatible objects ($M = 634$), $F(1, 28) = 34.5$, $p < 0.001$, $MSe = 3878$. The same pattern was evident, but not significant, in the accuracy data, $F(1, 28) = 3.3$, $p = 0.083$, $MSe = 24.0$. The experimental conditions affected both RTs, $F(2.1, 59.5) = 96.8$, $p < 0.001$, $MSe = 3630.2$, and error rates, $F(3, 84) = 10.0$, $p < 0.001$, $MSe = 20.9$, although the patterns were not identical (see Fig. 6). The viewing conditions had similar relative effects on performance with the exception of the long-term presentation condition. This produced the fastest RTs but the most

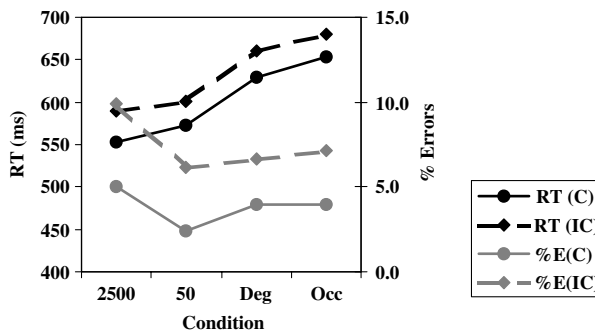


Fig. 6. The compatibility effect for response times and errors in Experiment 2 by condition. C = Compatible, IC = incompatible. 2500 = Unmasked object exposure for 2500 ms, 50 = unmasked object exposure for 50 ms, Deg. = object degraded by contrast reduction of 90%, Occ. = object occluded by grid.

errors. Of most interest was the grasp affordance compatibility effect which was again highly significant in both the RTs, $F(1, 28) = 43.5$, $p < 0.001$, $MSe = 2608$, and the error data, $F(1, 28) = 37.0$, $p < 0.001$, $MSe = 42.6$, but for neither measure did this vary significantly between viewing conditions (see Fig. 6).

The effect of the viewing conditions differed for the two object types. In the RT data the overall disadvantage for the smaller objects was reduced in the long-term presentation condition and increased in the degraded condition, $F(3, 84) = 15.1$, $p < 0.001$, $MSe = 725$. In the error data a similar increase was observed in the degraded condition but there was no reduction in the long-term presentation condition. There was, however, a reversal of the performance difference in the occluded condition where the smaller, precision compatible objects, were responded to more accurately, $F(3, 84) = 3.95$, $p = 0.011$, $MSe = 13.3$.

3.3. Discussion

Neither occlusion or low stimulus contrasts produced significant alterations in the pattern and magnitude of grasp compatibility, despite having significant overall effects on performance measures. As in Experiment 1, allowing the object to be visible during response selection and execution produced a similar compatibility effect to that obtained when the object representation had to be maintained without on-line visual support. In the contrast reduced condition, the time difference between the availability of object size information and object category would be exaggerated, allowing further time for putative irrelevant size codes to decay before the response was selected. There was no indication that this had any effect on the grasp compatibility produced. Similarly in the occluded condition there was no indication that adding a visual stimulus that disrupted the target object's affordance for grasping had any influence on the compatibility effect observed, although given the aforementioned lack of any real affordance from computer images this condition itself could be considered merely another degradation of the stimulus.

4. Experiment 3

Whether or not a graspable object is visible during response selection and execution has relatively little impact on the affordance effect elicited—as long as the object itself can be reliably identified. Similarly, degrading the viewing conditions, or adding a further visual stimulus that occludes the object and represents an obstruction to the affordance, makes little difference to the effect produced. This all points to their being a *sufficient* locus of the effect in the object representation itself. It does not need to be a current focus of the visual system, nor does the affordance it represents have to be literally possible. (This latter point, of course, also held in all those of our previous experiments where stimuli were presented on a computer monitor.)

The fast, transient, and automatic visuomotor processing associated with the dorsal system would not seem to be a necessary requirement. Instead it appears that long-term visuomotor associations between the object and successful interactions

are the source of the effect. As a stronger test of this hypothesis Experiment 3 examined the possibility that the grasp compatibility could be elicited from object words as well as images.

4.1. Method

4.1.1. Apparatus and design

The stimuli were 32 object slides (16 precision compatible and 16 power compatible) together with 32 slides of the same object's names. Within each grasp category half the pictures or names represented natural objects and half-manufactured objects. The objects used are listed in Appendix B. The mean letter length of the power compatible object names was 5.9 and the precision compatible objects 5.7. The objects were chosen with the aid of Snodgrass and Vanderwart's (1980) norms and as far as possible matched for typicality of category membership as well as word length. Presentation Mode (Picture or Word) and Category to response assignment were manipulated between subjects.

4.1.2. Participants

Eighty participants took part. Twenty were assigned to each Presentation Mode by Mapping combination.

4.1.3. Procedure

The procedure was the same as the 2500 ms timeout condition of the previous experiment. Subjects were instructed to make precision or power responses according to the names or pictures of the objects presented. If no response was made before the 2.5 s had elapsed the trial was terminated without replacement and a timeout error recorded.

4.2. Results

Seven subjects were excluded from the final analysis because of excessive error rates. The remaining 73 subjects were analysed in a mixed model ANOVA with two between subjects factors: Presentation Mode (Picture or Word) and Response Mapping (Natural = Precision/Manufactured = Power or the reverse). The two within subjects factors were Object Size (Small or Large) and Response (Precision or Power). There was a main effect of Presentation Mode with participants categorising images ($M = 565$) 46 ms faster than Words ($M = 612$), $F(1, 69) = 5.7$, $p = 0.02$, $MSe = 27, 301$. This difference was not apparent in the error data. Participants made more errors to small objects ($M = 3.4$) than to large ones ($M = 2.9$), $F(1, 69) = 4.6$, $p = 0.035$, $MSe = 4.9$, although there was no significant difference in the RT. Object size interacted with the Presentation Mode. For both RT, $F(1, 69) = 10.6$, $p = 0.002$, $MSe = 301.4$, and Error rates, $F(1, 69) = 11.2$, $p = 0.001$, $MSe = 4.9$, small objects produced better performance than large objects in the Image condition, but poorer performance in the Word Condition. There was also a main effect of Response, with faster reaction times (582 vs. 595 ms), $F(1, 69) = 12.2$, $p = 0.001$, $MSe = 1071.6$, and

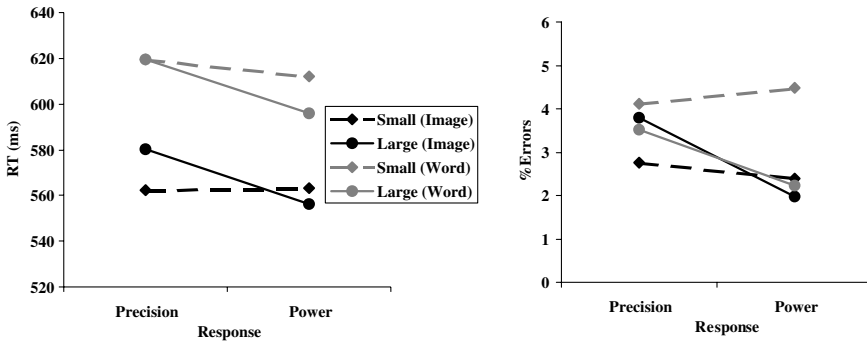


Fig. 7. Response Time and error data for Experiment 3 by Object Size, Response and Presentation Mode (Image or Word).

lower error rates (2.8% vs. 3.5%), $F(1, 69) = 10.2$, $p = 0.002$, $MSe = 4.2$, associated with Power responses.

Of most importance, however, was the Object Size by Response compatibility effect and its interaction with the Presentation Mode condition. Averaged over both images and words the compatibility effect was highly significant for both measures of performance. Reaction times for compatible trials were on average 10.1 ms faster, $F(1, 69) = 24.8$, $p < 0.001$, $MSe = 301.8$, and produced 0.8% fewer errors, $F(1, 69) = 5.5$, $p = 0.022$, $MSe = 8.1$, than incompatible trials. Most importantly there was no evidence that this compatibility effect differed significantly between Images or Words either for RT, $F(1, 69) = 1.2$, $p = 0.28$, $MSe = 301.8$, or Errors, $F(1, 69) = 0.031$, $p = 0.86$, $MSe = 8.1$. The pattern for each presentation mode is displayed in Fig. 7.

4.3. Discussion

Surprisingly, the compatibility effect obtained from the names of precision or power compatible objects was statistically indistinguishable from that obtained from images of those objects. This provides conclusive evidence that on-line visual processing of an object is not necessary to generate affordance-based compatibility effects. In contrast, what appears to be critical is the object–action association. An object’s associated actions can be partially activated regardless of the mode of access to the object representation.

5. General discussion

Experiment 1 showed that there was little evidence to support the notion that the on-line presence of a visual object was necessary to produce compatibility effects from an object’s affordance for action. Once the combined conditions of masking and stimulus duration allowed reliable object identification the compatibility effect remained constant. There was almost no evidence that increased viewing times increased the size of the effect.

Experiment 2 examined the effect under two additional types of stimulus disruption. The pattern observed here was similar to the longer exposure conditions of the previous experiments. Whilst the stimulus disruptions produced reliable effects on performance, the grasp compatibility effect itself was unaffected.

The data rule out the requirement that a visual object be present at the time response selection is completed for affordance compatibility effects to be induced. Any increases in such compatibility effects associated with longer viewing times and/or a lack of backward masking can be most parsimoniously explained by the associated increases in identification accuracy. Thus at the briefest stimulus exposure times and under masking conditions the compatibility effect was severely disrupted but so also was the participant's ability to accurately identify the target. Together with the fact that the compatibility effect tended not to increase once performance accuracy had stabilised, this implies that the route from which the compatibility effect emerges does not depend upon active visual input but from a maintained representation of the object. The role of the dorsal 'action stream', at least its on-line component is not implicated.

Experiment 3 showed there to be an equally strong effect from object words. Here of course, all immediately action-related visual input was absent, thereby ruling out any dependence on on-line visual input altogether. This furthermore rules out any dependence upon short-term visual memory although it leaves open the possibility that visual imagery could play a role. By themselves, the results from the first two experiments do not rule out the requirement that a visual object be present during the early stages of response selection operating in parallel with stimulus identification within a common coding scheme (e.g. Eimer, Hommel, & Prinz, 1995; Hommel, Müsseler, Aschersleben, & Prinz, 2001). The data from Experiment 3, however, argue strongly against the necessity even for a visual object to be present at any stage during the perception-action loop for these affordance effects to be generated.

The data force the conclusion that within an experimental set-up in which on-line reaching and grasping are not actually occurring the route through which these affordance effects are generated depends more upon stored knowledge of the object and its associated actions than upon the detailed physical parameters of the viewed object. This finding fits with Glover's (in press) interpretation of the dorsal-ventral distinction along control and planning lines. The systems involved in motor planning would appear to play a more critical role in generating affordance effects that do not depend critically on accurate on-line adjustments and parameterisation. Much as global action patterns themselves contribute to object knowledge (e.g. the action sequences examined in Rumiati & Humphreys (1998), Rumiati & Tessari (2002), Tessari & Rumiati (2002)) so also do low level action properties associated with grasp types. Such object-action knowledge is in the form of categories of action or action sequences rather than the finely tuned on-line control of actions during prehension.

A study by Chainay and Humphreys (2002) is of particular relevance here. These authors found systematic differences in decision times about actions ('would you make a twisting or pouring action with this object?') or context ('would you typically find this in a kitchen?') to visual objects or their names. They found that action

decisions were made significantly faster for visual objects relative to words whereas there was no difference between the modes of presentation for the contextual judgement. They concluded that there is a privileged access to action knowledge for objects over words; although they found no increase in this advantage when participants signalled their action judgement using a manipulandum that could be poured or twisted. This is somewhat at odds with our own results from Experiment 3 where we found no systematic differences between objects and words. However the two tasks are importantly different. In the Chainay and Humphreys task participants were explicitly asked to make action judgements (or contextual judgements) whereas in the present Experiment 3 the explicit question was a category judgement and the action relation was implicit in the mode of responding. Given that either the lexical or visual route is capable (in normal participants) of activating stored knowledge about actions any advantage for the visual route to this knowledge might not manifest itself if the primary task is not itself an action judgement. What our own data do show, however, is that either route to an object representation is sufficient to activate its affordance for a *category* of action. Furthermore when the object is not the target of an actual grasping action the basis for the affordance effect is most likely the stored object knowledge rather than the immediate physical stimulus properties that would guide the action when it was the target of a real action. Under normal viewing conditions presumably all sources of information would be used.

In our previous studies on affordance effects (Tucker & Ellis, 1998, 2001), the emphasis on dorsal system processing was probably misplaced. It is possible that dorsal system processes were responsible for the effects of object orientation (Tucker & Ellis, 1998) as this is a viewpoint dependent object property that, of necessity, must be derived from a currently viewed object if it is to serve any useful function in guiding action. However it is equally plausible that instances of oriented objects evoke broad categories of action based upon past interactions in similar (e.g. leftward or rightward) orientations—and to produce compatibility effects in a bi-manual task such categories could be as coarsely defined as a preferential hand. The present conclusions can thus only apply, with confidence, to intrinsic object properties and their relations to afforded actions. The relation between extrinsic object properties, such as orientation, and actions may depend more critically upon immediate visual information. In conclusion the present data suggest that object affordance effects in off-line tasks reflect the activation of stored action knowledge built up from a history of past interactions that have become integrated with the object representation itself (Ellis & Tucker, 2000; see also Hommel, 2002). This action knowledge is only broadly tuned and reflects classes of broadly specified actions in contrast to the finely tuned calibrations that take over during prehensile acts themselves.

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Appendix A. List of objects used in Experiments 1–2

Precision compatible		Power compatible	
Natural	Manufactured	Natural	Manufactured
Nut	Clothes Peg	Cucumber	Bottle
Mushroom	Pencil sharpener	Leek	Brush
Grape	Key	Parsnip	Chisel
Cherry	Match	Squash	Mallet

Appendix B. List of objects used in Experiment 3

Precision compatible		Power compatible	
Natural	Manufactured	Natural	Manufactured
Grape	Biro	Apple	Bottle
Hazelnut	Coin	Banana	Cup
Mushroom	Eraser	Carrot	Mallet
Pea	Key	Celery	Pliers
Peanut	Needle	Cucumber	Saucepan
Raisin	Teaspoon	Potato	Teapot
Tomato	Thimble	Pear	Trowel
Radish	Pencil	Lemon	Spanner

References

- Buxbaum, L. J., Sirigu, A., Schwartz, M. F., & Klatzky, R. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia*, *41*, 1091–1113.
- Chainay, H., & Humphreys, G. W. (2002). Privileged access to action for objects relative to words. *Psychonomic Bulletin & Review*, *9*, 348–355.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *Neuroimage*, *12*, 478–484.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1999). Action for perception: a motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1673–1692.
- Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: a necessary interaction between cognition and action. *Journal of Experimental Psychology—Human Perception and Performance*, *27*, 218–228.
- Eimer, M., Hommel, B., & Prinz, W. (1995). S–R compatibility and response selection. *Acta Psychologica*, *90*, 301–313.
- Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1737–1747.

- Ellis, R., & Tucker, M. (2000). Micro-affordance: the potentiation of components of action by seen objects. *British Journal of Psychology*, *9*, 451–471.
- Glover, S. (in press). Separate visual representations in the planning and control of actions. *Behavioral and Brain Sciences*.
- Goodale, M. A., & Humphrey, G. K. (1998). The objects of action and perception. *Cognition*, *67*, 181–207.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in the Neurosciences*, *15*, 20–25.
- Grèzes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, *4*, 212–222.
- 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.
- Handy, T. C., Grafton, S. T., Shroff, N. M., Ketay, S., & Gazzaniga, M. S. (2003). Graspable objects grab attention when the potential for action is recognized. *Nature Neuroscience*, *6*, 421–427.
- Hommel, B. (1994). Effects of irrelevant spatial S–R compatibility depend on stimulus complexity. *Psychological Research*, *56*, 179–184.
- Hommel, B. (1995). Stimulus–response compatibility and the Simon effect: toward an empirical clarification. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 764–775.
- Hommel, B. (2002). Responding to object files: automatic integration of spatial information revealed by stimulus–response compatibility effects. *Quarterly Journal of Experimental Psychology*, *55A*, 567–580.
- Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): a framework for perception and action planning. *Behavioral And Brain Sciences*, *24*, 849–878.
- Jeannerod, M. (1994). The representing brain: neural correlates of motor intention and imagery. *Behavioral and Brain Sciences*, *17*, 187–202.
- Klapp, S. T., & Hinkley, L. B. (2002). The negative compatibility effect: unconscious inhibition influences reaction time and response selection. *Journal of Experimental Psychology—General*, *131*, 255–269.
- Klatzky, R. L., Fikes, T. G., & Pellegrino, J. W. (1995). Planning for hand shape and arm transport when reaching for objects. *Acta Psychologica*, *88*, 209–232.
- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus–response compatibility—a model and taxonomy. *Psychological Review*, *97*, 253–270.
- Kosslyn, S. M. (1994). *Image and brain: the resolution of the imagery debate*. Cambridge, MA: MIT Press.
- Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, *379*, 649–652.
- Milner, A. D., & Goodale, M. A. (1993). Visual pathways to perception and action. *Progress in Brain Research*, *95*, 317–337.
- Phillips, J. A., Humphreys, G. W., Noppeney, U., & Price, C. J. (2002). The neural substrates of action retrieval: an examination of semantic and visual routes to action. *Visual Cognition*, *9*, 662–684.
- Pisella, L., Grea, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., Boisson, D., & Rossetti, Y. (2000). An ‘automatic pilot’ for the hand in human posterior parietal cortex: toward reinterpreting optic ataxia. *Nature Neuroscience*, *3*, 729–736.
- Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R., & Heafield, T. (1998). Visual affordances direct action: neuropsychological evidence from manual interference. *Cognitive Neuropsychology*, *15*, 645–683.
- Riddoch, M. J., Humphreys, G. W., & Price, C. J. (1989). Routes to action—evidence from apraxia. *Cognitive Neuropsychology*, *6*, 437–454.
- Rumiati, R. I., & Humphreys, G. W. (1998). Recognition by action: dissociating visual and semantic routes to action in normal observers. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 631–647.
- Rumiati, R. I., & Tessari, A. (2002). Imitation of novel and well known actions: the role of short-term memory. *Experimental Brain Research*, *142*, 425–433.
- Schlaghecken, F., & Eimer, M. (1997). The influence of subliminally presented primes on response preparation. *Sprache & Kognition*, *16*, 166–175.
- Shepard, R., & Meltzer, J. (1971). Mental rotations of three-dimensional objects. *Science*, *171*, 701–703.

- Sirigu, A., Cohen, L., Duhamel, J. R., Pillon, B., Dubois, B., & Agid, Y. (1995). A selective impairment of hand posture for object utilization in apraxia. *Cortex*, *31*, 41–55.
- 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.
- Tessari, A., & Rumiati, R. (2002). Motor distal component and pragmatic representation of objects. *Cognitive Brain Research*, *14*, 218–227.
- Tlauka, M., & McKenna, F. P. (1998). Mental imagery yields spatial stimulus–response compatibility. *Acta Psychologica*, *98*, 67–79.
- Tucker, M., & Ellis, R. (1998). On the relations of seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 830–846.
- Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, *8*, 769–800.
- Wexler, M., Kosslyn, S. M., & Berthoz, A. (1998). Motor processes in mental rotation. *Cognition*, *68*, 77–94.