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Visual object affordances: Object orientation

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Abstract

Five experiments systematically investigated whether orientation is a visual object property that affords action. The primary aim was to establish the existence of a pure physical affordance (PPA) of object orientation, independent of any semantic object–action associations or visually salient areas towards which visual attention might be biased. Taken together, the data from these experiments suggest that firstly PPAs of object orientation do exist, and secondly, the behavioural effects that reveal them are larger and more robust when the object appears to be graspable, and is oriented in depth (rather than just frontally) such that its leading edge appears to point outwards in space towards a particular hand of the viewer.

PsycINFO classification: 2323; 2330; 2340; 2346

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1. Introduction

1.1. Overview

Gibson (1979) famously argued that a perceiver's sensorimotor capabilities highly constrain the kind of visual information that gets accessed. The affordance hypothesis is central to this; the visual system might directly detect visual information about the behavioural possibilities afforded to us by objects and surfaces. Decades later – in one form

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or another – the notion of affordances continues to attract special interest (e.g. Michaels, 2003) and inspire contemporary theories of perception.

This paper examines one potential source of affordance – an object's orientation – and asks whether it is an object property that acts as a 'pure physical affordance'. By pure physical affordance (PPA), we mean an affordance that is solely revealed by the physical structure or arrangement of the object. While the term affordance is convenient and much-used, it is not even clear whether PPAs exist at all. In fact, as we discuss later, visual stimuli used in previous investigations have confounded orientation with semantic sources of affordance and sources of attentional bias. Using carefully selected visual object stimuli, the experiments in this paper go some way towards establishing that PPAs of object orientation do in fact exist.

1.2. Some behavioural effects of object orientation

Several behavioural studies have reported facilitatory effects associated with an object's orientation, thus providing general support for the affordance hypothesis. However, as we argue in this section, semantic and attentional factors prevent these studies from serving as evidence of PPAs.

1.2.1. Orientation confounded with semantics

Humphreys and Riddoch (2001) reported data from a patient (MP) with spatial neglect. MP's object detection improved when the object was cued by a description of its associated action (e.g. "find the object you could drink from") rather than its identity (e.g. "find the cup"). This improvement dissipated, however, when the object's orientation was away from the viewer (i.e. the handle pointed away from the viewer) such that it was less likely to afford interaction. Such data led Humphreys and Riddoch to argue that there is a direct pragmatic route from vision to action in the brain, realised by action templates that are activated by object affordances.

Riddoch, Edwards, Humphreys, West, and Heafield (1998) reported a case of 'utilisation' behaviour whereby patient ES often failed to respond with the task-appropriate hand when reaching for a cup (the rule demanded reaching with the left hand to cups on the left, and with the right hand to cups on the right). ES reached instead with the hand that was afforded by the orientation of the cup's handle (e.g. even though the cup was on the left, when the cup's handle pointed to the right, ES would reach with the right hand). Related findings have been discussed by Riddoch, Humphreys, and Edwards (2000) and Humphreys and Riddoch (2000).

Studies using normal participants have also demonstrated that an object's orientation affords action. Tucker and Ellis (1998) reported a study in which the participants judged whether the household objects were upright or inverted and responded accordingly with a left or right hand key press. Spatial key presses were faster and more accurate when they corresponded with the task irrelevant orientation of the object (e.g. a saucepan with its handle pointing leftwards promoted better left hand response performance). Symes, Ellis, and Tucker (2005) have shown that this orientation-dependent spatial compatibility (OSC) effect is dissociable from other spatial compatibility effects such as the Simon effect (Simon, 1969). In addition, the OSC effect also extends to remembered objects (Derbyshire, Ellis, & Tucker, 2006). In contrast to Tucker and Ellis' (1998) suggestion that the affordance of object orientation evokes a specific motor response bias (e.g. for the limb most suited to perform the afforded action), Phillips and Ward (2002) argued instead that affordances are coded in a more abstract fashion. In support of this abstract coding view, Phillips and Ward (2002) demonstrated OSC effects using crossed hands and even foot responses (in their study prime symbols that were superimposed over target objects specified which spatial response to make).

We suggest that these kinds of studies do not provide evidence of PPAs, since the stimuli used have tended to be common household objects (such as cups) that have obvious action connotations. We all know, for example, that the handle is the functional part of a cup that is supposed to be grasped. Creem and Proffitt (2001) suggested that picking an object up appropriately by its handle requires a necessary interaction between cognition and action. Such facilitatory effects may therefore owe as much to the object's functional, semantically derived affordance as they do to any potentially available PPAs.

In cases where the orientation of an *abstract* object has been manipulated (rather than common household objects), there has also been a potential semantic confound. In the well-known visuomotor priming studies of Craighero and colleagues, for example (Craighero, Fadiga, Rizzolatti, & Umiltà, 1998, 1999), clockwise or counterclockwise grasps of real-world target bars were facilitated when they were compatible with the orientation of a prime object (an outline of a rectangle oriented ±45°). It is possible that the goal-set and nature of the task (i.e. grasping a real-world oriented bar) engendered the visually similar prime objects with some action-related meaning.

1.2.2. Orientation confounded with attention

As Anderson, Yamagishi, and Karavia (2002) have pointed out, affordance studies have generally investigated visually asymmetrical objects. They argued that visual asymmetry is likely to induce an attentional bias, and it may be this attentional bias (whereby attention is shifted to a specific location on the object) that is responsible for the generation of motor signals. This explanation is well-served by theories of attention that suppose a link between motor programming and attentional control (see Schneider & Deubel, 2002, for a recent review). Schneider and Deubel's (1995) visual attention model – VAM, for example, assumes that the allocation of visual attention leads to motor programming (e.g. of the oculomotor system).

In a series of reaction time experiments in which line drawings of objects and non-objects were judged to be clockwise or anticlockwise from their 'normal' orientation, Anderson et al. (2002) reported facilitation of responses that were spatially compatible with the object's visually salient feature – even if this contradicted the object's semantic affordance. It is possible, however, that these results arose because participants used the visually salient feature as a cue for judging orientation. In contrast, a notable feature of Tucker and Ellis' (1998) and other OSC studies has been the task-irrelevancy of object orientation. OSC effects occur *even though* orientation is task-irrelevant. Nevertheless, the attention-directing hypothesis is a plausible alternative to the affordance hypothesis and it remains the case that the object stimuli used in affordance studies have tended to be asymmetrical, with visually salient areas that might bias attention.

1.3. Experimental questions addressed in this study

It was therefore the main aim of the present study to test the hypothesis that an object's orientation acts as a PPA. We tested this hypothesis by setting up OSC conditions using object stimuli that firstly did not have any semantic affordances (only novel, functionally neutral objects were used), and that secondly were controlled for any visually salient areas. If an object's orientation activates components of a reach-to-grasp movement, this should be reflected in the speed and/or accuracy of spatial key presses (which to an extent mimic the initiation of a reach-to-grasp movement with a particular hand).

In addition, we systematically varied the visual complexity of the stimuli (see Fig. 1 for examples), in an attempt to vary the strength of our predicted OSC effects. Our prediction here was that the more realistic, three-dimensional and graspable an object appeared, the stronger its PPA would be.

The same basic method applied to each experiment: On each trial a visual stimulus appeared centre screen that was oriented ±45° from the perpendicular. The participants were instructed to respond as fast as possible with a left key press when the object's surface pattern resembled a 'wobbly' wood grain, and a right key press when it resembled a 'straight' wood grain (object orientation was therefore completely task-irrelevant). The stimulus orientation and surface pattern were selected at random and with equal probability. As a secondary research question, we introduced different stimulus onset asynchronies (SOAs) in order to examine the time course of any OSC effects found. When the object's surface pattern was 'neutral' (the SOA stimulus), the participants waited until this pattern

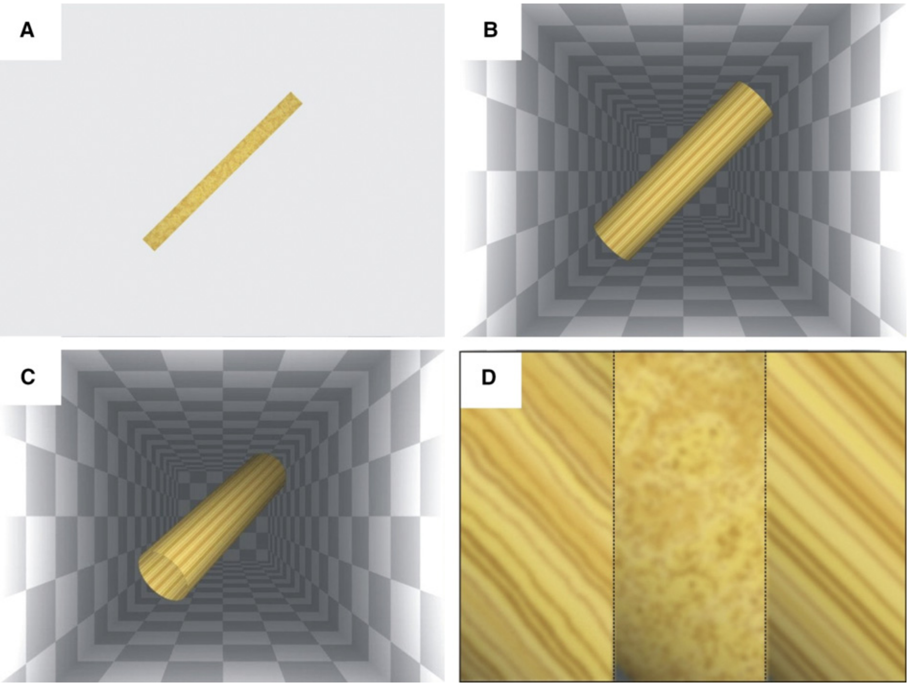


Fig. 1. Stimuli with −45° left-down orientations as used in Experiments 1–5 (the mirror image 45° right-down orientations are not shown). (A) Experiment 1 (visual symmetry): A rectangular shape with apparent two-dimensional (2D) structure embedded in a 2D background; (B) Experiments 2 and 4 (visual symmetry): A cylinder with apparent three-dimensional (3D) structure embedded in a 3D background; (C) Experiments 3–5 (visual asymmetry): The same cylinder from (B) additionally rotated in the depth plane so as to point towards the viewer. (D) Response judgements were based on the surface pattern of the stimulus (wobbly, neutral and straight patterns are shown, respectively).

changed (after 0, 800 or 1200 ms) into a wobbly or straight pattern (see Fig. 1D for an illustration of each pattern). There is some evidence that the size of OSC effects builds in a linear fashion with viewing time (e.g. Phillips & Ward, 2002). Specifically, spatial responses that are compatible with the orientation of the object get faster as object viewing time increases. We were interested in seeing whether this same pattern would occur using visual stimuli that had been controlled for semantic and attentional factors.

Referring back to the objects in Fig. 1, it may not be immediately obvious which orientation would be compatible with a particular response. Why should we expect that the '−45° left-down' orientation of these objects is more compatible with one hand than the other for example? There are at least two reasons for supposing that −45° left-down oriented stimuli are compatible with left responses, and 45° right-down oriented stimuli are compatible with right responses. Firstly, the nearest end of a −45° left-down stimulus (the left end) is closest to the viewer's left hand (and similarly, the nearest end of a 45° right-down rectangle is closest to the viewer's right hand). This nearest end might activate the corresponding response side. Secondly, the ease of a would-be-grasp of a given oriented stimulus is not equal for the two hands. A left-hand grasp, for example, would be less biomechanically awkward when made to a −45° left-down object than to a 45° right-down object, and vice versa for the right hand (see Johnson, 2000). As such, objects with −45° left-down orientations should afford left-handed actions, and objects with 45° right-down orientations should afford right-handed actions.[1]

2. Experiment 1

As outlined in Section 1, we hypothesised the existence of a PPA relating to an object's orientation (i.e. existing independently of functional affordances and visually salient areas). Specifically, we predicted that the angle of an object's axis of elongation (i.e. the angle of its orientation) would facilitate spatially compatible responses. For reasons described in Section 1, we predicted that a −45° left-down orientation would facilitate left responses, and a 45° right-down orientation would facilitate right responses.

In this first experiment, we used as our oriented stimulus a visually simplistic object (a patterned rectangle) that was set in a grey background. Since this abstract object did not look like it could be picked-up or interacted with (in other words, we would not intuitively expect it to have a strong PPA), we assumed that any OSC effect obtained would be negligible in size (i.e. an effect size <10 ms). Typically, OSC effect sizes deriving from oriented every-day objects have been of the order of about 10–20 ms (e.g. Tucker & Ellis, 1998; Symes et al., 2005).

2.1. Method

2.1.1. Participants

The 21 paid participants (mean age 21.2 years) that took part in this experiment consisted of six males (all right-handed) and 15 females (13 right-handed, two left-handed). All had normal or corrected-to-normal vision, and were naive as to the purpose of the study.

[1] It is not our intention to empirically distinguish between these two possibilities in this study. We present them simply as possibilities that recommend directional predictions for potential OSC effects.

2.1.2. Apparatus and materials

The participants sat in a small darkened room directly in front of an RM 16-in. colour monitor (the screen resolution was set to 1024 × 768 pixels with a refresh frequency of 85 Hz). Key press responses were made with the index finger of each hand, using the two CTRL keys on a standard QUERTY keyboard (index fingers were separated by 27 cm). The distance from head to screen was ∼50 cm, and ∼30 cm from hands to screen. RTs and errors (violations of the response rule) were recorded to a data file for off-line analysis.

The background image was a uniform grey fill of the whole screen (∼visual angle: 36.0° × 27.5°). The six stimulus images consisted of this same grey background with a rectangle located in its centre (∼visual angle of the rectangle: 1.6° × 17.2°). The rectangle could have two possible orientations (±45°) and three possible surface patterns (neutral, wobbly, straight). These patterns resembled a wood-grain effect, and were coloured accordingly (a yellow/brown colour). The log mean luminance of pixels for these images was as follows: background (0.902), background with neutral patterned rectangles (0.898), background with wobbly and straight patterned rectangles (0.897).

2.1.3. Design and procedure

The participants were instructed to press the left CTRL key when the stimulus pattern was wobbly, the right CTRL key when straight, and not to respond to a neutral pattern (but instead wait until it changed into a wobbly or straight pattern). A trial consisted of an inter-trial interval of 1.5 s, during which time a white fixation cross (∼visual angle: 0.6°) was centrally displayed over the background. This was then replaced by an SOA stimulus (i.e. a neutral patterned rectangle) which remained in view for 0, 800 or 1200 ms. The SOA stimulus was then replaced by a target stimulus (i.e. the same rectangle now had a wobbly or straight pattern). The target stimulus remained in view until the participant responded, or until 3 s had passed and the trial was given time-out. Response errors were signalled by a tone.

Twenty practice trials were followed by 396 experimental trials. The order of stimulus presentation was randomised in one block, and the factors of SOA (0, 800, 1200), orientation (−45° left-down, 45° right-down) and response (left, right) were fully balanced (e.g. 33 presentations × 3 SOAs × 2 orientations × 2 responses = 396 trials).

2.2. Results

Errors and RTs more than two standard deviations[2] from each participant's condition means were excluded from this analysis and the analyses of all the other experiments were reported. 3.5% of the trials were removed as errors and 3.3% of the trials were removed as outliers, leaving 93.2% of the raw data as correct response trials. The condition means for correct response RTs for each participant were subjected to a repeated measures ANOVA with the within subjects factors of SOA (0, 800, 1200 ms), orientation (−45° left-down, 45° right-down) and hand of response (left, right). The condition means for the frequency of errors (excluding time-outs) for each participant were also subjected to a repeated measures ANOVA.

[2] Standard deviations for each participant were based on their pooled condition SDs. This outlier criterion typically removes about 4% of the data.

The error analysis did not reveal any statistically significant results. The RT analysis revealed main effects of SOA, $F(2,40) = 11.661$, $p < .0001$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 563, 514 and 505 ms, respectively) and response, $F(1,20) = 17.917$, $p < .0001$ (mean RTs for left responses = 540 ms and right responses = 515 ms). There was also an interaction between SOA and response, $F(2,40) = 20.998$, $p < .0001$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 585, 525 and 510 ms, respectively, for left responses, and 542, 503 and 500 ms, respectively, for right responses). The interaction of primary interest, however (between orientation and response), did not reach statistical significance, $F(1,20) = 1.795$, $p = .195$. An examination of the means revealed that RTs for left hand responses were identical for both orientations (540 ms). When the hand of response was right, however, performance did follow the predicted direction – RTs were faster for 45° right-down orientations (510 ms) rather than −45° left-down orientations (520 ms).

2.3. Discussion

This first experiment investigated whether the task irrelevant orientation of a rectangle would facilitate spatially compatible responses. It did not, and consequently there was no evidence to suggest that the orientation of this stimulus constituted a PPA. This finding concurs with the attention-directing hypothesis (Anderson et al., 2002), which does not predict response facilitation in the absence of a salient visual feature or area towards which attention might be biased.

While the orientation of meaningful 2D objects may evoke semantic affordances (e.g. a line drawing of a saucepan), there is no evidence that the orientation of an abstract 2D object (e.g. a rectangle) evokes a PPA. The purely physical characteristics of a rectangle's orientation may only afford interaction in a highly abstract manner that does not directly influence action planning.

The perceived dimensionality of an object can influence the kind of actions that one makes towards it (Castiello, Bonfiglioli, & Bennett, 1996, 1998), and 2D shapes do not intuitively afford a wide range of actions (indeed, under Gibson's (1979) theory, they do not afford any actions). In contrast, objects that do intuitively afford action in the real world have 3D structure. An object that appears as a real-world object (i.e. it appears to be 3D and graspable) may, therefore, be more likely to produce an OSC effect. A second experiment tested this possibility.

3. Experiment 2

In this experiment, the 2D rectangle was replaced with a cylinder that had apparent 3D structure. A chequered room was used as a background to reinforce the illusion that this object was 3D and 'real'. Its orientation, however, was the same as the 2D rectangle (it was oriented ±45° from the perpendicular), and again, it was visually symmetrical such that there was no visually salient area towards which attention might be directed.

3.1. Method

3.1.1. Participants

The 20 new paid participants (mean age 21.8 years) who took part in this experiment consisted of seven males (all right-handed) and 13 females (12 right-handed, one left-handed). All had normal or corrected-to-normal vision, and were naive as to the purpose of the study.

3.1.2. Apparatus and materials

The apparatus was identical to the first experiment. The materials were entirely new. The background image was a grey and white chequered room which gave the impression of depth in space (~visual angle: 36.0° × 27.5°). The six stimulus images consisted of this same chequered background with a cylinder of apparent 3D structure located in its centre (~visual angle of the cylinder: 4.1° × 17.3°). The cylinder could have two possible orientations (±45°) and three possible surface patterns (neutral, wobbly, straight). The log mean luminance of pixels for these images was as follows: background (0.494), background with neutral, wobbly and straight patterned cylinders (0.519).

3.1.3. Design and procedure

The design and procedure were identical to the first experiment.

3.2. Results

2.9% of the trials were removed as errors and 3.8% of the trials were removed as outliers, leaving 93.3% of the raw data as correct response trials. Condition means were computed, and as previously, two ANOVAs were performed (one on correct response RTs and the other on percentage errors).

The error analysis did not reveal any statistically significant results. The RT analysis revealed a main effect of SOA, $F(2,38) = 107.862$, $p < .0001$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 573, 524 and 507 ms, respectively) and an interaction between SOA and response, $F(2,38) = 3.660$, $p = .035$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 576, 525 and 502 ms, respectively, for left responses, and 569, 523 and 512 ms, respectively, for right responses).

Of primary interest was an interaction between orientation and response, $F(1,19) = 5.027$, $p = .037$. When the hand of response was left, mean RTs were faster for −45° left-down orientations (533 ms) rather than 45° right-down orientations (536 ms). When the hand of response was right, mean RTs were faster for 45° right-down orientations (529 ms) rather than −45° left-down orientations (539 ms).

3.3. Discussion

The interaction between orientation and response revealed slightly faster RTs when the orientation of the object was spatially compatible with the hand of response. This small OSC effect (effect size: 6.5 ms) presumably does not reflect a semantic affordance (the cylinder had no semantic connotations or functional elements such as a protruding handle), and there was no obvious scope for attentional bias (the cylinder was visually symmetrical and therefore did not have a salient feature or area towards which attention might be directed). As such we conclude from this experiment that when an object appears to have 3D structure, the angle of its axis of elongation (i.e. its orientation) provides sufficient action-relevant information to evoke a small PPA. The next experiment attempted to increase the size of this effect by further manipulating the cylinder.

4. Experiment 3

In this experiment, the visual complexity of the oriented object was increased by additionally rotating the cylinder 45° about its centre in the depth plane. Now the cylinder had the visual appearance of pointing in space towards a particular hand of the viewer, potentially maximizing the PPA of object orientation. A natural bi-product of this rotation was that the cylinder became visually asymmetrical, providing an area of visual salience on its leading edge. Consequently, this experiment did not differentiate between affordance and attention. Nevertheless, given a potentially more potent PPA and a visually salient area that could potentially attract visual attention, we predicted that this visually asymmetrical cylinder would produce a larger OSC effect.

4.1. Method

4.1.1. Participants

The 20 new paid participants (mean age 20.5 years) who took part in this experiment consisted of six males (all right-handed) and 14 females (13 right-handed, one left-handed). All had normal or corrected-to-normal vision, and were naive as to the purpose of the study.

4.1.2. Apparatus and materials

The apparatus was identical to the previous experiments. The materials were based on those used in Experiment 2. The chequered background image was the same. The six stimulus images consisted of this same chequered background with a cylinder of apparent 3D structure located in its centre (~visual angle of the cylinder: $4.2° \times 14.8°$). The visually asymmetrical cylinder had two possible orientations (±45°) and three possible surface patterns (neutral, wobbly, straight). The log mean luminance of pixels for these new images was as follows: background with neutral, wobbly and straight patterned cylinders (0.511).

4.1.3. Design and procedure

The design and procedure were identical to the previous experiments.

4.2. Results

3.2% of the trials were removed as errors and 4.7% of the trials were removed as outliers, leaving 92.1% of the raw data as correct response trials. Condition means were computed, and as previously, two ANOVAs were performed (one on correct response RTs and the other on percentage errors).

The only effect found in errors was a main effect of SOA, $F(2,38) = 5.136$, $p = .011$ (SOAs of 0, 800 and 1200 ms produced mean errors of 3.9%, 3.2% and 2.5%, respectively). The RT analysis revealed main effects of SOA, $F(2,38) = 10.527$, $p < .0001$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 559, 535 and 512 ms, respectively) and response, $F(1,19) = 8.950$, $p = .007$ (mean RTs for left responses = 541 ms and right responses = 529 ms). There was also an interaction between SOA and orientation, $F(2,38) = 4.235$, $p = .022$ (SOAs of 0, 800 and 1200 ms produced mean RTs of 551, 539 and 511 ms, respectively, for −45° left-down orientation, and 567, 531 and 513 ms, respectively, for 45° right-down orientation).

The interaction of primary interest, however, was between orientation and response, $F(1,19) = 15.454$, $p = .001$. When the hand of response was left, mean RTs were faster for −45° left-down orientations (533 ms) rather than 45° right-down orientations (549 ms). When the hand of response was right, mean RTs were faster for 45° right-down orientations (525 ms) rather than −45° left-down orientations (534 ms). As predicted, the OSC effect was larger in this experiment (effect size: 12.5 ms) than it was in Experiment 2 (effect size: 6.5 ms). This difference was not supported, however, in a cross-experimental analysis of Experiments 2 and 3 (in which Experiment was added as a between subjects factor). An interaction between Experiment, orientation and response was not statistically significant, $F(1,38) = 2.083$, $p = .157$, suggesting that Experiment as a factor had not modulated the OSC effect.

4.3. Discussion

Intrinsic to the new visually asymmetrical cylinder stimuli of this experiment were the possibilities of a more potent PPA and an attentional bias towards the cylinder's visually salient leading edge. These possibilities led us to predict a larger OSC effect than the one found in the previous experiment (which used visually symmetrical cylinders). Superficially at least, the results appeared to support our prediction; the OSC effect size was almost twice as large as it had been in Experiment 2. Nevertheless, this difference was not supported in a cross-experimental analysis of the data. With a view to clarifying this result, Experiment 4 compared the visually symmetrical and asymmetrical cylinders within a single experiment.

5. Experiment 4

In order to test whether the different cylinders in Experiments 2 and 3 produced quantitatively different OSC effects, we directly compared them in this fourth experiment. Because the factor of SOA did not modulate the OSC effect in any of the previous experiments, and in order to maintain sufficient OSC condition instances within a manageable number of trials, there were no SOA manipulations in this experiment.

5.1. Method

5.1.1. Participants

The 16 new paid participants (mean age 20.3 years) who took part in this experiment consisted of four males (three right-handed, one left-handed) and 12 females (11 right-handed, one left-handed). All had normal or corrected-to-normal vision, and were naive as to the purpose of the study.

5.1.2. Apparatus and materials

The apparatus was identical to the previous experiments. The materials were those used in Experiments 2 and 3 (except that no SOA stimuli were used).

5.1.3. Design and procedure

The participants were instructed to press the left CTRL key when the stimulus pattern was wobbly and the right CTRL key when straight. A trial consisted of an inter-trial interval of 1.5 s, during which time a white fixation cross (~visual angle: 0.6°) was centrally displayed over the background. This was then replaced by a target stimulus that remained in view until the participant responded or until 3 s had passed and the trial was given timeout. Response errors were signalled by a tone.

A brief practice period was followed by 240 experimental trials. The order of stimulus presentation was randomised in one block, and the factors of cylinder symmetry (symmetrical, asymmetrical), orientation (−45° left-down, 45° right-down) and response (left, right) were fully balanced (e.g. 30 presentations × 2 symmetries × 2 orientations × 2 responses = 240 trials).

5.2. Results

5.2% of the trials were removed as errors and 4.1% of the trials were removed as outliers, leaving 90.7% of the raw data as correct response trials. Condition means were computed, and as previously, two ANOVAs were performed (one on correct response RTs and the other on percentage errors). The error analysis did not reveal any statistically significant results. The RT analysis revealed a number of interactions. There was an interaction between cylinder symmetry and response, $F(1,15) = 12.767$, $p = .003$. Symmetrical cylinders produced faster mean RTs for right (547 ms) rather than left (565 ms) responses, and asymmetrical cylinders produced faster mean RTs for left (538 ms) rather than right (562 ms) responses. There was an interaction between orientation and response, $F(1,15) = 8.348$, $p = .011$. When the cylinder orientation was −45° left-down, mean RTs were faster for the left hand (550 ms) rather than the right hand responses (560 ms). When the cylinder orientation was 45° right-down, mean RTs were faster for the right hand (549 ms) rather than the left hand responses (554 ms).

A three-way interaction between cylinder symmetry, orientation and response, $F(1,15) = 9.683$, $p = .007$, revealed that asymmetrical cylinders had been largely responsible for the interaction reported above (orientation × response). Symmetrical cylinders did not reproduce the small OSC effect that they had previously produced in Experiment 2; the mean RTs of left responses were almost identical for both orientations (−45° left-down = 566 ms; 45° left-down = 565 ms), as were the mean RTs of right responses (−45° left-down = 547 ms; 45° left-down = 547 ms). The asymmetrical cylinders, however, did produce a 'large' OSC effect (effect size: 16 ms) in keeping with the results of Experiment 3. Thus when the hand of response was left, mean RTs were faster for −45° left-down orientations (533 ms) rather than 45° right-down orientations (543 ms). When the hand of response was right, mean RTs were faster for 45° right-down orientations (551 ms) rather than −45° left-down orientations (573 ms).

5.3. Discussion

The three-way interaction between cylinder symmetry, orientation and response suggested that symmetrical and asymmetrical cylinders had indeed produced differential effects; only asymmetrical cylinders produced an OSC effect. This experiment therefore provided additional support for our prediction that visually asymmetrical cylinders should produce the largest OSC effects. Experiment 5 attempted to establish the degree to which this reflected the potentially more potent PPA of orientation, or the potentially attention-biasing visually salient area of the cylinder.

6. Experiment 5

As we have already argued, the small OSC effect found in Experiment 2 presumably reflected a PPA of orientation rather than any attentional bias, since the cylinders used were visually symmetrical. An influence of attentional bias, however, cannot be ruled out when considering the larger OSC effects found with *asymmetrical* cylinders in Experiments 3 and 4. To test this possibility, we repeated Experiment 3 with an additional detection task designed to test the influence of a cylinder's visually salient area. In the detection task, an asymmetrical cylinder was presented for a brief interval (SOAs of 800 or 1200 ms) and then a target dot appeared on one end of the cylinder. Upon detecting the dot, participants responded by pressing the spacebar.

If visual attention is indeed automatically drawn to the visually salient area of an asymmetrical cylinder, then dot-detection times should be faster when the dot's location corresponds to that salient area (i.e. because attention should already be there). The size of any *attention*-dependent spatial compatibility effect found in the detection task can be directly compared to any OSC effect found in the judgement task (thus giving us an idea of the relative contributions of attention and PPA).

6.1. Method

6.1.1. Participants

The 19 new paid participants (mean age 20.7 years) who took part in this experiment consisted of six males (all right-handed) and 13 females (12 right-handed, one left-handed). All had normal or corrected-to-normal vision, and were naive as to the purpose of the study.

6.1.2. Apparatus and materials

The apparatus was identical to the previous experiments. The materials were those used in Experiment 3 (i.e. visually asymmetrical cylinders). On detection task trials (which are described in the next section), a white circular dot with a black surround was superimposed over one or other end of the cylinder (visual angles: white interior $\sim 1.2°$; with black surround $\sim 1.7°$).

6.1.3. Design and procedure

The experiment consisted of two separate and distinct tasks – a judgement task and a detection task. The judgement task was based on Experiment 3 (although there were only two SOA variations). In the detection task, participants were required to press the spacebar as soon as they detected a dot (both hands rested on the space-bar, thus removing any spatial dimension of the response). The two tasks alternated sequentially in 10 blocks of 40 trials, and this sequence started with the judgement task for eight participants and the detection task for 12 participants. A black screen with text instructions indicated the commencement of a new block and the responses required (e.g. "Wobbly/L – Straight/R" for judgement blocks, or "Dot/Spacebar" for detection blocks). To aid task switching, L and R labels were affixed to the left and right CTRL keys.

A brief practice session incorporating both tasks was followed by 400 experimental trials. For each task, the order of stimulus presentation was randomised within each of its five blocks of 40 trials, and the factors of SOA (800 ms, 1200 ms), orientation (−45° left-down, 45° right-down) and location (judgement task: left, right *response* location; detection task: left, right *dot* location) were fully balanced (e.g. 5 presentations × 2 SOAs × 2 orientations × 2 locations = 40 trials).

6.2. Results

2.0% of the trials were removed as errors (all from the judgement task) and 3.9% of the trials were removed as outliers, leaving 94.1% of the raw data as correct response trials. The condition means for correct response RTs for each participant were subjected to a repeated measures ANOVA with the within subjects factors of task (judgement, detection), SOA (800, 1200 ms), orientation (−45° left-down, 45° right-down) and response/dot location (left, right). The result of primary import[3] was the statistically significant three-way interaction between task, orientation and response/dot location, $F(1,18) = 9.387$, $p = .007$. This interaction revealed an OSC effect in the judgement task, but no comparable attention-related spatial compatibility effect in the detection task. This apparent difference between tasks was clarified when the data from each task were examined separately.

6.2.1. Judgement task trials

The judgement task condition means for correct response RTs for each participant were subjected to a repeated measures ANOVA with the within subjects factors of SOA (800, 1200 ms), orientation (−45° left-down, 45° right-down) and response location (left, right). Two statistically significant effects were found – a main effect of SOA, $F(1,18) = 34.622$, $p < .0001$ (SOAs of 800 and 1200 ms revealed mean RTs of 501 and 482 ms, respectively), and an interaction between orientation and response location, $F(1,18) = 9.095$, $p = .007$. When the hand of response was left, mean RTs were faster for −45° left-down orientations (490 ms) rather than 45° right-down orientations (503 ms). When the hand of response was right, mean RTs were faster for 45° right-down orientations (484 ms) rather than −45° left-down orientations (489 ms).

The judgement task condition means for the frequency of errors for each participant were also subjected to a repeated measures ANOVA. This revealed one statistically significant finding – an interaction between orientation and response location, $F(1,18) = 4.739$, $p = .043$. In accordance with the OSC effect found in RTs, when the hand of response was left, mean errors were lower for −45° left-down orientations (3.2%) rather than 45° right-down orientations (4.5%). When the hand of response was right, mean errors were lower for 45° right-down orientations (3.5%) rather than −45° left-down orientations (5.1%).

6.2.2. Detection task trials

The detection task did not produce any errors. The detection task condition means for correct response RTs for each participant were subjected to a repeated measures ANOVA with the within subjects factors of SOA (800, 1200 ms), orientation (−45° left-down, 45° right-down) and dot location (left, right). This revealed one statistically significant result – a main effect of SOA, $F(1,18) = 120.751$, $p < .0001$ (SOAs of 800 and 1200 ms revealed mean

[3] Other results included main effects of task, $F(1,18) = 299.671$, $p < .0001$ and SOA, $F(1,18) = 160.867$, $p < .0001$; and interactions between task × SOA, $F(1,18) = 7.892$, $p = .012$; task × orientation, $F(1,18) = 5.731$, $p = .028$; orientation × response/dot location, $F(1,18) = 4.448$, $p = .049$; and SOA × orientation × response/dot location, $F(1,18) = 4.601$, $p = .046$.

RTs of 315 and 284 ms, respectively). An interaction between orientation and dot location did not approach statistical significance, $F(1, 18) = .847$, $p = .369$, and its pattern of means did not resemble an attention-related spatial compatibility effect. When the dot location was left, for example, mean RTs were slightly faster for 45° right-down orientations (298 ms) rather than −45° left-down orientations (301 ms). In other words, dots located on the visually non-salient farthest end of the cylinder were detected slightly faster than dots located on the visually salient nearest end of the cylinder. Furthermore, when the dot location was right, mean RTs were the same for both orientations (299 ms), thus showing no difference between dots located on the visually salient or non-salient end of the cylinder.

6.3. Discussion

Since the detection task failed to provide any evidence of an attentional bias towards the visually salient end of a cylinder, the most parsimonious interpretation of the OSC effect is therefore an affordance-based one. We suggest that the OSC effects found for asymmetrical cylinders (as obtained in Experiments 3–5) were evoked by the PPA of a cylinder's orientation. As further support for this interpretation, an additional RT analysis was performed in which each participant's condition means in the detection task were used as covariates in the ANOVA of the judgement task data (again using the within subjects factors of SOA, orientation and response location).[4] By partialling out any purely attentional effect in this way, the remaining statistical estimate for an attentionally unbiased OSC effect suggested that the relevant interaction between orientation and response location had nevertheless survived, $F(1, 18) = 7.388$, $p = .014$. The adjusted means for this effect remained the same as those reported earlier.

7. General discussion

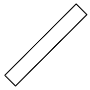
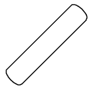
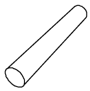
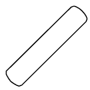
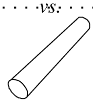
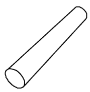
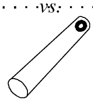
7.1. Primary findings

The precise source of OSC effects has been intractable in previous studies of object orientation. Any potential evidence of a PPA of object orientation has been confounded by the possibility of semantically derived object–action associations and attentional biases towards visually salient object areas. The five experiments reported in this paper used novel, virtual objects (i.e. semantically neutral objects) that were variously controlled for visual saliency. The data, which are summarised in Table 1, provided a range of supports for our primary hypothesis that a PPA of object orientation does exist.

Furthermore, given that the visually salient end of a cylinder does not appear to have biased attention to any appreciable extent (Experiment 5), we are compelled to offer an affordance-based account of the differential pattern of OSC effects found when using progressively more visually complex object stimuli. Taken together, the data from these five experiments tend to support our hypothesis that the more realistic, three-dimensional and graspable an object appears to be (by virtue of both its physical structure and its orientation), the more potent its PPA is. Thus, an apparently 3D cylinder oriented only in the frontal plane produced a small OSC effect (Experiment 2), whereas an abstract 2D rectangle

[4] We would like to thank Bernhard Hommel for recommending this analysis to us.

Table 1
Mean RTs (ms) for OSC effects in each experiment

Experiment	Stimuli	Orientation (degrees)	Location*	RTs (ms)	OSC effect size (ms)
1		-45	L	540	5
		45	L	540	
		-45	R	520	
		45	R	510	
2		-45	L	533	6.5△
		45	L	536	
		-45	R	539	
		45	R	529	
3		-45	L	533	12.5△
		45	L	549	
		-45	R	534	
		45	R	525	
4		-45	L	566	-0.5
		45	L	565	
		-45	R	547	
		45	R	547	
	vs.				
		-45	L	533	16△
		45	L	543	
		-45	R	573	
		45	R	551	
5		-45	L	490	9△
		45	L	503	
		-45	R	489	
		45	R	484	
	vs.				
		-45	L	301	-1.5
		45	L	298	
		-45	R	299	
		45	R	299	

* Location refers to left–right responses for the judgement tasks in Experiments 1–5 and to the left–right location of the dot for the detection task in Experiment 5. △ denotes a statistically significant OSC effect.

that was oriented in the same way (Experiment 1) did not. Similarly, an additional rotation in depth of this 3D cylinder (such that it now had the appearance of pointing out in space towards a particular hand of the viewer) produced apparently larger (Experiments 3–5) and more robust (Experiment 4) OSC effects. This apparent strengthening of PPA can be appreciated visually in Fig. 2, where OSC effect sizes have been averaged across experiments in terms of the stimuli used (visually symmetrical oriented stimuli from Experiments 1, 2 and 4, and visually asymmetrical oriented stimuli from Experiments 3–5).

7.2. Secondary findings

Phillips and Ward (2002) reported that the size of OSC effects derived from the photographs of real-world functional objects builds in a linear fashion with viewing time. We investigated whether the same time course would arise from functionally and semantically neutral stimuli. SOAs of 0, 800 and 1200 ms did not modulate the OSC effect in any of the

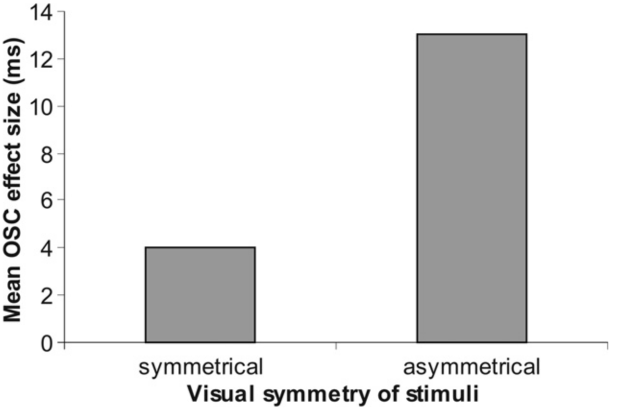


Fig. 2. OSC effect sizes averaged across experiments in terms of the visual symmetry of the stimuli presented.

experiments reported. This serves as preliminary evidence that the time course of OSC effects that could have derived in part from semantic object–action associations may differ from those derived from PPAs.

7.3. Conclusions

We conclude that PPAs can exist in their own right, independent of semantic associations and attentional biases. Furthermore, the strength of this PPA appears to intensify in line with aspects of an object's appearance that quite intuitively *afford* action. An object's orientation in particular (as determined by the angle of its axis of elongation) appears to evoke a PPA that can be observed behaviourally by proxy of an OSC effect.

In terms of controlling for 'attention', however, the present paper has merely attempted to preclude (Experiments 1 and 2), observe (Experiments 3–5) and test (Experiment 5) the impact of visually salient object areas. Such controls can only hint at other aspects of visual attention such as object-based attention (e.g. O'Craven, Downing, & Kanwisher, 1999). It does appear likely, however, that any attentional processes that may have been associated with the OSC effects reported in this paper were directed at an object, and not at a location (on an object). This complements recent evidence from our laboratory suggesting that the affordance of a manipulable object's orientation is encoded when attention is directed towards the object as a whole, and not, for example, towards its handle (Vainio, Ellis, & Tucker, in press).

Importantly then, we do not conclude from our present study that object affordances operate in an attentional vacuum. On the contrary, we have speculated elsewhere (Symes et al., 2005) on the likelihood that attention and affordance are intimately related mechanisms. We suspect that visual attention is a mechanism that is far too important (and pervasive) *not* to be at some level involved in deriving object affordances. Common-coding schemes account well for such interactions and those relating to other similarly important mechanisms such as intention (e.g. Hommel, Müsseler, Aschersleben, & Prinz, 2001). Indeed, mechanisms of attention often appear to be action-centred, and it may be the case that 'selection-for-action' and 'selection-for-perception' are necessarily coupled (Deubel, Schneider, & Paprotta, 1998; Schiegg, Deubel, & Schneider, 2003).

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