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Rapid communication

Implicit processing of shadows

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Abstract

Using synthetic objects, I investigate whether recognition performance is sensitive to different features of cast and attached shadows. Participants were required to recognise familiar objects presented to central vision while the presence, position and shape of cast and attached shadows were systematically manipulated. Costs in response time were found for naming objects in incongruent lighting and shadow conditions, that is, when the object was presented with a cast shadow that originated from a different object and when it was also non-congruently illuminated (e.g. attached shadow indicating that the source of light was from the left, and cast shadow indicating that the source of light was from the right). © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Cast shadows; Attached shadows; Lighting; Identification

1. Introduction

Cast and attached shadows are a fundamental presence in natural visual scenes. Cast shadows, caused by the blockage of light from a light source by the object, or part of the object, project onto a surface (extrinsic cast shadow), or onto a part of the object itself (intrinsic cast shadow). Attached shadows instead are surface patches facing away from the light source. Attached shadows are frequently the source of '3-dimensionality' of rendered objects, but both types of shadow provide cues to the shape of objects. For example, it is known that under some object and illumination conditions, the shadow cast by an object can make the spatial relationship between the object and its surroundings explicit to the observer as efficiently as the shape or the size of the object itself (Yonas, Goldsmith, & Hallstrom, 1978; Mamassian, Knill, & Kersten, 1998; Tarr, Kersten, & Bulthoff, 1998). Furthermore, as elegantly demonstrated by Kersten, Knill, Mamassian, and Bulthoff (1996), cast shadows can provide valuable information about the 3D structure of objects, and the motion of an object's cast shadow determines the perceived 3D trajectory of the object. Adjusting the motion of a shadow is sufficient to induce dramatically different apparent trajectories of the object casting the shadow (Kersten, Mamassian, & Knill, 1997). More recently, Braje and colleagues (Braje, Kersten, Tarr, & Troje, 1998; Braje, Legge, & Kersten, 2000) explored the effects of shadows on recognition of natural objects. No effects of shadows on naming latency and accuracy were found. Performance was not affected by the presence of shadows.

Here, I report one experiment in which the perception of an object is impaired when it appears accompanied by an incongruent cast shadow—cast shadow from another object—or by incongruent illumination with respect to the cast shadow—cast and attached shadows each the result of lighting from opposite sides of the object. The crucial issue is whether there is a variation in response times (RTs) with incongruent cast shadows, or with incongruent directions of lighting for the cast and attached shadows. Observers' performance showed that both incongruent cast shadows and incongruent directions of lighting for cast and attached shadows increased the recognition time for familiar objects.

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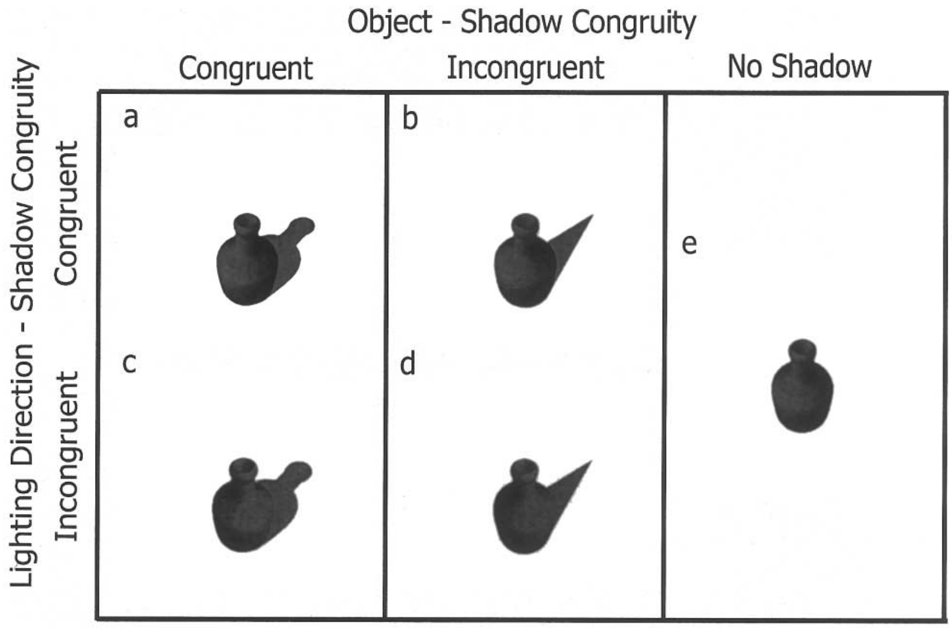

Fig. 1. Examples of displays for the object-shadow-lighting combinations. The shape of the cast shadow could be congruent (a) or incongruent (b) with the shape of the object. Lighting was also manipulated: for congruent lighting, the direction of lighting and the position of the cast and attached shadows were congruent (c). For incongruent lighting, the direction of lighting and the position of the cast and attached shadows did not correspond (d). Panel 'e' represents the object without cast shadows. Please note that the objects were red, and the background was grey.

2. Methods

The stimuli used for these experiments were 20 objects (geometrical shapes and familiar objects; for an example, see Fig. 1; for the entire list of objects, see Appendix A) synthesised using a 3D rendering package POVRAY. They were illuminated with ambient and point light sources either from the left or from the right, in order to avoid the effects of up/down illumination changes on perceived shape. Lighting conditions were created as follows. The objects rested on an x–y plane, with y pointing out of the picture; x and z the horizontal and vertical directions. The camera's viewpoint was oriented 45° about the x-axis, above the x–y plane. The left and right light sources were elevated 45° and placed $\pm 34°$. The reflectance model used an ambient reflectance of 0.2. The luminance of each object ranged from 16 to 36 cd/m^2 (from the lighter to the darker part). The luminance for the shadow was 22 cd/m^2.

The shadows-without-objects were generated by moving the objects towards thelight source, out of the camera's field of view. The objects were scaled so that the generated shadows were the same size as the original object. These shadow and object images were then combined to create the final image. The object was displayed with a congruent (derived from the object; Fig. 1a) or incongruent (derived from any of the other 19 objects used for the experiment; Fig. 1b) cast shadow. Furthermore, the object was illuminated either congruently with the side of projection of the cast shadow (for example, attached shadow resulting from light from the right, and left-projecting cast shadow; Fig. 1c) or incongruently with the side of projection of the cast shadow (for example, attached shadow resulting from light from the right, and right-projecting cast shadow; Fig. 1d). The objects without cast shadow but with attached shadow were also presented (Fig. 1e). The area subtended by the objects, including the shadows, was 7.8° × 7.8° of visual angle.

Twenty participants took part in the experiment. They were asked to look at the screen for the entire length of each trial, and were instructed to wait for the appearance of the object (with or without any shadow, depending on the condition) in the centre of a computer screen. They viewed the objects binocularly from a distance of approximately 70 cm from the screen. Participants were tested in the following experimental conditions:

1. cc: An object rendered with an attached shadow was presented with its natural cast shadow (*congruent*), and the direction of lighting that produced the attached shadow and the direction of the lighting that produced the cast shadow were *congruent* (Fig. 1a).
2. ic: An object rendered with an attached shadow was presented with an *incongruent* cast shadow, and the direction of lighting that produced the attached shadow and the direction of the lighting that produced the cast shadow were *congruent* (Fig. 1b).
3. ci: An object rendered with an attached shadow was presented with its natural cast shadow (*congruent*),

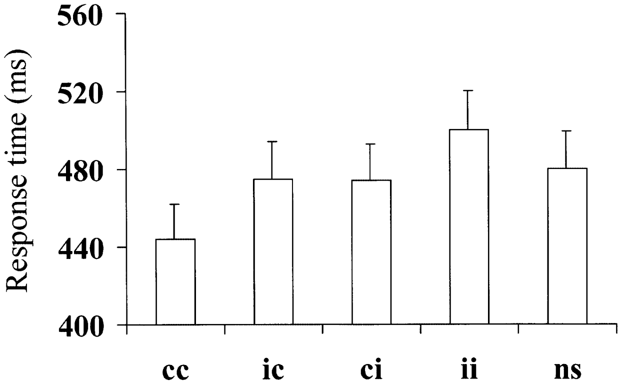

Fig. 2. Mean RTs for the five experimental conditions. cc = congruent cast shadow and congruent lighting; ic = incongruent cast shadow and congruent lighting; ci = congruent cast shadow and incongruent lighting; ii = incongruent cast shadow and incongruent lighting; ns = no cast shadow. Error bars show the standard error.

and the direction of lighting that produced the attached shadow and the direction of the lighting that produced the cast shadow were *incongruent* (Fig. 1c).

4. ii: An object rendered with an attached shadow was presented with an *incongruent* cast shadow, and the direction of lighting that produced the attached shadow and the direction of the lighting that produced the cast shadow were also *incongruent* (Fig. 1d).
5. An object rendered with an attached shadow was presented without a cast shadow (Fig. 1e).

In all experimental conditions, participants were required to report as quickly as possible the identity of the presented object.

The end of the trial was taken as either the time of response emission, or 2000 ms after the stimulus presentation, if no response was made. The subsequent trial was presented after an interval of 2000 ms. Each participant first completed 80 practice trials followed by four blocks of 100 trials where all the experimental conditions were randomised. The duration of each block was no longer than 15 min, and all blocks were separated by a 5–10 min rest period. Trials in which errors of anticipation (reaction time less than 150 ms) or non-responses (or those made over 2000 ms) occurred were automatically re-set to the end of the block to be re-presented in random order. Catch trials, where the object would not appear, were also included in order to further prevent expectancy or practice effects. Vocal RTs were taken from the time of the stimulus onset to the time of response emission, and were recorded by means of a microphone.

Each participant's data were submitted to the following editing procedures. Trials with RTs outside the range encompassed by the mean ± 3 standard deviations (S.D.) were eliminated (3%). In order to meet criteria for ANOVA data distribution and sphericity were also controlled for. The error rate was 2%. An ANOVA with condition (cc, ic, ci, ii, ns) as a within-subjects factor was performed. Newman–Keuls post-hoc contrasts were also performed to explore means of interest (alpha level: 0.05).

3. Results

As shown in Fig. 2, the time to correctly identify the object was longer when both lighting and shadow shape were incongruent than when both lighting and shadow shape were congruent [500 vs. 444 ms; $F(4,95) = 10.33$, $P < 0.001$]. Intermediate values resulted for the condition where the cast shadow was incongruent and the lighting was congruent (474 ms), and for the condition where the cast shadow was congruent and the lighting was incongruent (475 ms). RT was longer when the 3D object was presented without cast shadow than when presented with a congruent cast shadow (480 vs. 444 ms).

The present results suggest that the perception of incongruent shadow and/or incongruent lighting gave rise to a distorted visual representation of a familiar object, and this interfered with the natural shadow/lighting/object interaction, thus slowing object identification.

4. Discussion

In this investigation of whether human object recognition is sensitive to shadows and lighting, there are several key results: (i) in the presence of incongruent cast shadows, participants were slower to recognise objects; (ii) participants were slower to recognise objects when the lighting direction indicated by attached shadows was incongruent with the position of the cast shadows; (iii) when presented with objects without cast shadows, participants were slower to recognise the objects than when a congruent cast shadow was present.

I began by asking whether the processing of cast shadows and attached shadows is necessary for object recognition. Previous studies have demonstrated an increase in response times with changes in lighting direction (Tarr et al., 1998). Along the same lines, the present findings suggest that contradictory information about the direction of lighting in the presence of attached and cast shadows may influence object recognition. Consider the significant interaction between type of cast shadow and type of lighting (indicated by attached shadows), which suggests an increase in response times with incompatibility of lighting direction and the position of the shadows.

Cast shadows and attached shadows may thus be included in long-term 'object files' where the interactions between the light source and the casting object are played out to provide information about object structure (Kersten et al., 1996). This assumption can be plausible if one takes into account recent image-based theories of recognition, where it is advanced that high-level object representations retain much of the information present in the input image (Bulthoff, Edelman, & Tarr, 1995; Edelman, 1995; Gauthier & Tarr, 1997).

In the displays used in the experiment described, the information about the object interacts with the information about the shadow, and it is not used independently from it. If this latter were the case, RTs for the object presented without a cast shadow should have been similar to those for the object presented with a congruent cast shadow. However, results show that in the latter case, RTs were faster. This demonstrates that objects and cast shadows are linked to improve recognition. A possible explanation lies in the fact that efficient object recognition is the product of interactions between, and grouping of, the cast shadow and the object. This grouping seems to occur more efficiently when the cast shadow has a shape compatible with the shape of the object, or possibly when the shadow belongs to the class of possible cast shadows for that object. In this situation, grouping occurs independently from shape, but still allows for a coherent percept. At first, the present results seem in contrast to the findings by Braje and colleagues (2000), who found that the recognition process for natural objects (fruits) was invariant to the luminance patterns caused by shadows. That is, performance was not affected by the presence of shadows. However, the difference in the displays and the stimulus material used for these two experiments does not allow a direct comparison between the present study and the study by Braje et al. (2000). Further, Braje et al. (2000) did not manipulate shadow shape and lighting as done in the present study.

An alternative explanation for the present results is that the cost found for the processing of incongruent cast shadow is the product of interference. A substantial amount of research has demonstrated that in many situations, object features are analysed, even when they are irrelevant to the current behaviour of the organism. These studies show that the presence of irrelevant distractors can interfere with responses to a relevant selected object. One of the best examples of such interference is the Stroop effect (Stroop, 1935), where the response time to name the colour of the ink of a colour word is increased by the irrelevant-to-the-task meaning of the word. In the present experiments, shadows may act as distractors if they are interpreted as a competing object in the scene. However, if this were the case, a cost should be evident also for the congruent shadow condition, where a competing object is still present (i.e. the congruent shadow). Thus, the process of selection includes both the object and its shadow. However, how this processing is under selective attentional control is yet to be determined.

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Appendix A. List of stimuli used

Apple
Banana
Bottle
Calculator
Can
Cylinder
Cross
Eraser
Fork
Glass
Glove
Jug
Knife
Mandarin
Mug
Pen
Pyramid
Sphere
Tennis racket
Vase

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