EFFICIENT OR INEFFICIENT PROCESSING OF SHADOWS?
A CHANGE BLINDNESS STUDY

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Abstract

A change detection experiment is reported in which we addressed whether cast shadows of simple objects engage attentional processing using a flicker one-shot technique. On each trial, participants were shown two images separated by a blank frame, and asked to report whether a change had occurred in the second image or not. Images consisted of 12 synthetic objects casting shadows spatially arranged in a fan-shaped configuration. A change was present in only 50% of trials and consisted of one of the objects casting a shadow with an incongruent shape, a shadow with a different lighting direction, or both. Two conditions were created: a real shadow 3D condition, and a 2D condition (obtained through reversed contrast polarity). Change detection performance was overall poor, although higher in the real shadow condition than in the negative image condition. We conclude that cast shadows are processed inefficiently, but significantly better than 2D shapes.

The extent to which shadows are encoded and processed by the visual system has been the focus of intensive study in visual perception. One line of research has assessed the extent to which processing of shadows occurs in a fast and efficient manner by means of the visual search paradigm.

Elder *et al*. (2004) had participants reporting the presence or absence of a target defined as the only item possessing a cast shadow embedded in an array of distractor items with attached shadows only, or vice versa. As a control condition they used the very same images with inverted contrast polarity, so that they did not meet the so called *darkness constraint* (regions are interpreted as shadows only if they are darker than the surrounding background, cfr. Rensink & Cavanagh, 2004). The results showed almost flat RT × set-size functions for stimuli with *darkness constraint* satisfied only, irrespective of whether the target was a cast- or an attached-shadow singleton. Elder *et al*. concluded that both attached-shadow targets and cast-shadow targets can pop-out from the background and consequently can be processed in an efficient manner. Rensink and Cavanagh (2004) showed, across a wide range of visual search experiments, that finding a target defined as a singleton in the orientation of the cast shadow embedded in a display of identical objects casting shadows with the same orientation lead to positive RT × set-size functions, suggestive of inefficient search. In light of these findings, Rensink and Cavanagh (2004) argued that shadows are indeed identified rapidly, but then quickly discarded, as shown by the fact that orientation of regions interpreted as shadows were apparently difficult to access respect to identical non shadows area.

In a more recent study, Ostrovsky et al. (2005) have further tested the ability of the visual system to detect illumination inconsistencies in shadows, crucially using distractor items homogeneous in illumination direction but heterogeneous with respect to orientation. The results showed that performance was very poor, suggesting that shadows are not salient for the human visual system.

To sum up, because visual search studies have provided mixed results, we have taken a different methodological perspective by using a different experimental paradigm, that is change detection. Change detection was employed in order to estimate whether change detection performance increases when the change involves the cast shadow of an object with respect to a control condition. In the change detection paradigm, it is well known that attention shifting to the location of the task-relevant stimulus (i.e., the change) can be hindered by interposing a blank frame in between the original and the modified stimulus display. However, it has been shown that change blindness is reduced (i.e., change detection performance increases) whenever manipulations aimed at increasing the attentional priority of the changing object are implemented. In particular, change blindness seems to decrease when the salience of the changing stimuli is increased (e.g., Wright, 2005). In the present study we reasoned that because salient stimuli are less likely to undergo change blindness, then testing the ability of participants in detecting a change in a cast shadow may allow us to test the degree to which cast shadows are salient for the visual system. Critically, two conditions were created: a "real" shadow condition, and a control condition in which contrast polarity was reversed, which resulted in a negative image in which shadows were likely perceived as a 2D contrast image (e.g., Elder *et al.*, 2004; Tarr *et al.*, 1998) because of the violation of the darkness constraint (see Rensink & Cavanagh, 2004). The general prediction was that if shadows are really salient cues for the visual system, then detecting a change in the "real" shadow condition should be relatively less prone to change blindness with respect to the control condition.

Experiment

Method

Participants. Thirty-four students (aged 19-30 years, 11 males) from University of Padua took part in the experiment for partial course credit or as volunteers. They reported normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli. An IBM-compatible Pentium computer was used for controlling the timing of events, generating stimuli and recording responses. Participants sat in a dimly lit room, at a viewing distance of about 60 cm from a 17-inch colour monitor (1024 × 768, 60 Hz). All stimuli consisted of 12 objects (6 spheres and 6 pyramids) with light grey colour surface (RGB 95%, in each stimulus the objects surface colour was homogeneous) in a fixed spatial arrangement on a middle-grey background (RGB 50%). The number of the spheres and pyramids were balanced in each quadrant (that is, each quadrant contained exactly 1 sphere and 2 pyramids or vice versa). The overall image was included in a rectangle area of 24 per 24 cm, so it was about 22.6 deg of visual angle wide, whereas each single object measured about 1.5 cm and appeared 1.4 deg of visual angle wide. All stimuli were images in 256 levels grey-scale obtained through photo-retouch operations from three physically coherent shadows images. This latter stimuli were synthesized using 3D rendering software (Persistence of Vision 3.6, see Fig. 1). They were distinct from one another only for the different positions of the light source, labelled as central light position, middle-right position and corner-right position. All the remaining stimuli were obtained with photo-retouch operations from the first three ones using a 2D image editing software (Paint Shop Pro 7.0).

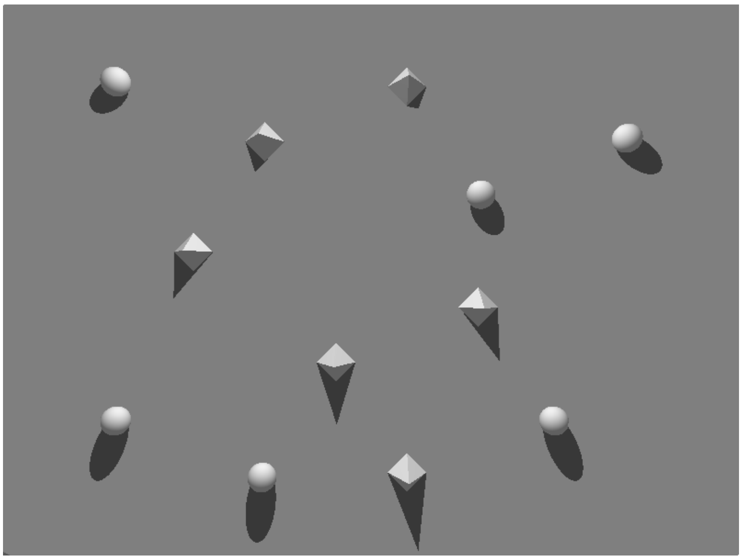

Figure 1. Physically coherent shadows stimulus with central light position.

Three possible inconsistencies were used to produce a change between two successive images. The light direction inconsistencies of one cast shadow was obtained with the substitution of the physically correct shadow with the one obtained at the very same conditions with another light source position. Specifically, central light position was used instead of middle-right position, middle-right position instead of corner-right position and corner-right position instead of central light position. Similarly, the form inconsistencies of the cast shadow was obtained with the substitution of the physically correct shadow with the one obtained by POVray rendering at the very same conditions (i.e., identity of source light position and object positions) with an inconsistent object, specifically, a sphere instead of a pyramid or vice versa. Finally, inconsistencies of both form and light direction of cast shadow were obtained simply by combining the two operations explained above.

Procedure. In order to measure the salience of inconsistent cast shadows we adopted the change detection paradigm in the flicker "one-shot" variant (Rensink, 2002). A higher salience of target stimulus generally leads to a reduction in change blindness, so that change detection performance can be used as an index of the attentional priority of target stimulus. Each trial consisted of two images presented in close temporal proximity and separated by a blank frame. The participants were asked to report whether the second image was the same as the first (no-change trial) or not (change trial) as accurately as they could. Figure 2 illustrates the three different kind of inconsistent shadows we used ("real" shadow condition and negative 2D contrast image). Combining the 3 possible shadow inconsistencies (light direction, shadow form and both) with 12 objects presented in the stimuli and 3 different positions of the light source, we obtained 216 (108 positive and 108 negative) different target stimuli. Each of these stimuli, preceded or followed by its appropriate coherent-shadow mate, constituted a change trial, whereas two identical consistent or inconsistent shadow stimuli constituted a no-change trial. A random procedure intermixed change and no-change trial and balanced change trials (consistent-inconsistent and inconsistent-consistent shadows) as well as no-change trials (consistent-consistent and inconsistent-inconsistent shadows). In the beginning of training and experimental sessions, observers were shown textual display instructions supported with oral explanations. It was emphasized that change and no-change trials occurred with the same probability and that they should perform the task as accurately as possible. The assignment of response key (left versus right) to response category (change

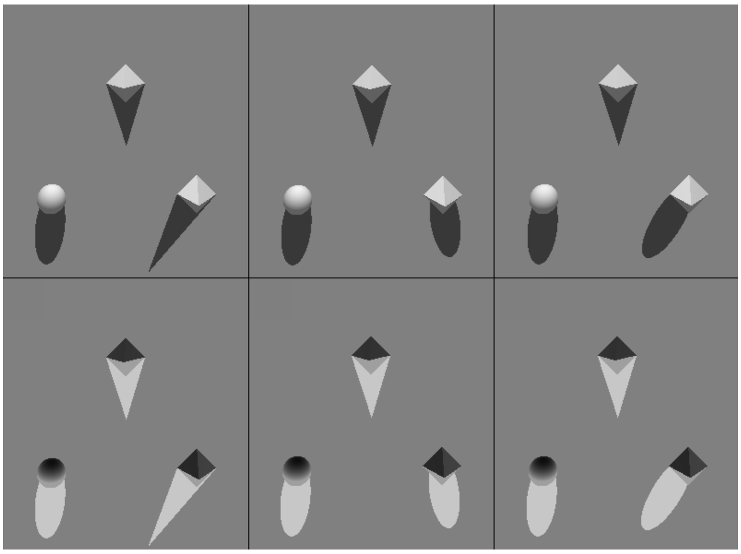

Figure 2. The three different kind of inconsistency of shadows in a “real” shadow condition (fist line) and negative 2D contrast image (second line).

versus no-change trial) was counterbalanced between subjects. Every trial consisted of the following sequence of events:
(i) a white blank frame for 1000 ms
(ii) a 100 ms high-frequency tone (1000 Hz)
(iii) a black fixation cross on white background in the centre of the screen for 1000 ms
(iv) a consistent or inconsistent shadow image for 400 ms
(v) a white blank frame for 300 ms
(vi) a consistent or inconsistent shadow image related with the first one (see above experimental design) for 400 ms
(vii) a white blank frame until the subject’s answer.
Immediately after of the observer’s answer a feedback text (“Correct”/“Incorrect”) was presented. Observers were administered a training session in one block of 36 trials. The experiment consisted of 3 blocks of 144 trials (72 change and 72 no-change trial) with a total number of 432 trials. Observers could rest between every block. The whole experiments, including instructions and practice block, took about 40 minutes. The entire experimental procedure (controlling timing of events and recording responses) was done using E-Prime software (E-Prime 2002 Psychology Software Tools).

Results

The analyses refer to change trials, as no-change trials served no purpose to test our predictions. Two observers who performed under the choice threshold on change trials accuracy or no-change trials accuracy were dropped.
Overall, observers correctly reported a change on 58% of change trials in a upright contrast polarity (shadow condition) and 52% in reversed contrast polarity (no-shadows condition). Figure 3 shows that accuracy was slightly higher when both light direction and form inconsistence was present. Form inconsistence result the most difficult to be detected. A two-way Analysis of Variance with shadow condition and type of inconsistency as factors performed on proportion of correct responses revealed a significant main effect of shadows

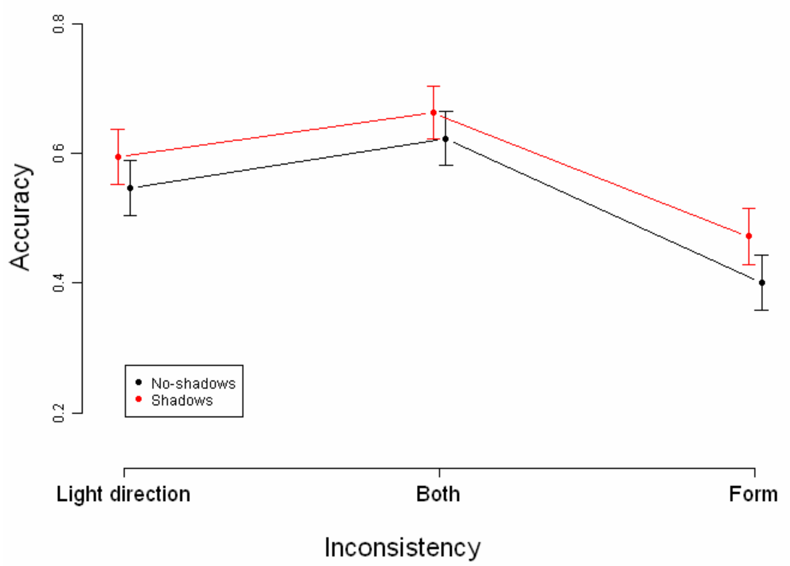

Figure 3. Accuracy due to inconsistence shadows shadows in a “real” shadow condition (Shadows) and negative 2D contrast image (No-shadows).

condition ($F_{1,33}$= 11.76, $p<.01$). Paired t tests revealed a significant difference between the means of the shadows/no-shadows levels for each single inconsistency condition (light direction, form and both) was found ($t_{33} = 2.2$, $p< 0.05$, $t_{33} = 2.4$, $p< 0.05$, $t_{33} = 3.15$, $p< 0.01$, respectively).

Discussion

The aim of the present study was exploring the extent to which cast shadows are encoded and processed by the visual systems. Previous studies provided mixed evidence as regards shadows salience and were mainly focused on the inconsistency of the orientation of a cast shadow with respect to the light source position (cf., Rensink & Cavanagh, 2004, Aks & Enns, 1992; Mamassian, 2004; Enns & Rensink 1990). To address this issue we adopted a different paradigm. In particular, we implemented a change detection paradigm based on the widely shared assumption that change detection requires the allocation of spatial attention towards the change (e.g., Rensink et al., 1997) and then the observers' performance can be a used to index whether and to what extent cast shadows are salient for the visual system. In order to avoid a possible confounding between illumination direction and shape orientation we used 3D computer-generated images with cast shadows spatially arranged in a fan-shaped configuration. This choice allowed us to use ecological stimuli with shadows fully congruent in direction with respect to the light source, but heterogeneous as regards orientation, shape and dimension. Finally, we manipulated not only light direction, but also the form of the cast shadows, alone or combined together.

Overall performance was rather poor. However, the results showed an overall reliable advantage in the trials with a cast shadow with respect the no-shadow control. This higher performance in change detection support the hypothesis that cast shadows possess, at least to some extent, a higher salience and, consequently, some degree of attentional priority compared to 2D surfaces of identical shape.

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