Shadows Affect Eye Movements in Visual Judgment Tasks

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Abstract

Research has suggested that observers, when looking at scenes with multiple illumination levels, tend to avoid shadowed regions in the images. This result was obtained in experiments using psychophysics and when using eye-tracking methodology. However, in such demonstrations participants were asked to estimate color properties. In the present study, we introduced cognitive tasks applied to images partially covered with a shadow. Participants, while looking at the photographed faces, judged age, beauty and profession of the depicted people. The eye movement measures (first fixation location, number of fixations, and dwell time) showed that even under such high-level cognitive tasks, the visual system has a preference for non-shadow regions.

Keywords: lightness; eye-movements; judgments.

Introduction

The human visual system shows the remarkable ability to accurately extract information of a visual scene while discarding influences of the light source that illuminates it. One demonstration of this ability is color constancy, reflecting the visual systems' ability to recognize colors despite ever-changing viewing conditions. (Arend & Reeves, 1986; Kraft & Brainard, 1999). The relevant conditions in the case of color recognition are orientation and distance to the light source, the illuminant's spectral qualities, the illumination level, and the gradients as well as cast illumination (i.e. shadows and spotlights). In most cases, color constancy can be achieved effortlessly and with negligible errors. However, color constancy seems to dramatically fail in laboratory settings when tested in a classical "constancy experiment". In such lab situations, a target matched in a spotlight produces significantly lighter matches than the same target shown in a shadow. Hence, in laboratory settings perception is determined by the momentary viewing conditions, while in everyday situations familiarity seems to be more important. This discrepancy suggests that in everyday conditions, perception strongly relies on cognitive factors.

Psychophysical studies showed that the lightness matches appear to be more strongly influenced by the illuminated region of a scene or an object (Zdravković, Economou, & Gilchrist, 2006). Recent studies have shown that the overall shade of an object is dictated by the portion presented in the higher illumination (Golz, 2010; Toscani, Valsecchi, & Gegenfurtner, 2013a, 2013b). These studies also show that observers tend to spend more time gazing the part in the higher illumination.

Finally, it has been shown that even when gazing at natural scenes observers tend to avoid shadows (Tatler, Baddeley, & Gilchrist, 2005). Latter eye tracking studies, however, did not control for other aspects of the shaded areas and tended to low-level features while ignoring the interpretation of scenes in terms of light sources and cast shadows.

In contrast, the present study introduces shadows into meaningful images and employs tasks that are unrelated to lightness or color perception. We used human faces partially covered with a cast shadow and we probed into high-level cognitive aspects of the stimuli, distracting participants away from low-level features of the images. In particular, we asked participants to judge the age, beauty and profession of the photographed people.

Faces were used as stimuli for our study, because it is known that observers looking at faces produce a fixed fixation pattern (Althoff & Cohen, 1999). For example, studies have suggested that observers tend to direct their first eye movement to just below the eyes (Hsiao & Cottrell, 2008), although individual differences can be found (Peterson & Eckstein, 2013).

Participants saw three versions of each image: one image with a shadow on the left side of the face, one image with a shadow on the right and one image without a shadow. The main manipulation (shadow on one side of the image) should demonstrate whether participants tend to avoid looking at shadowed regions. The image without the shadow will serve as a baseline.

Methods

Participants

Twenty-one female students from the University of Aberdeen (aged between 16 and 25 years) participated in return for course credit or without receiving reimbursement. Participants reported normal or corrected to normal vision. All participants signed an informed consent.

Apparatus

Stimuli were presented on a Dell 19 inch flat screen, placed at a distance of 77 cm from the observers, set to a spatial resolution of 1024 by 768 pixels and a 60 Hz refresh rate. Stimulus presentation was controlled by a Dell Optiplex PC. The camera of an Eyelink 1000 desk-mount system was placed below the screen at a distance of 66cm from the chin and forehead rest.

Eye movement data collection was controlled by a second PC (LanBox Lite). Participants held their forehead against the forehead rest, and sat with their head slightly above the chin rest, so that verbal responses were possible.

Stimuli

Each trial started with a drift correction target, presented on the vertical midline, 6.50 deg above or below the center of the display (randomly chosen). A face stimulus was presented in the middle of the screen after the experimenter confirmed fixation of the drift correction target.

Face stimuli consisted of 22 male and 22 female black and white photographs (Color Ebner database; Ebner, 2008). The photographs were all scaled back to 8.02 deg by 13.0 deg of visual angle. A darker region covering one half of the photograph was added using Photoshop, creating an appearance of a cast shadow, covering half of the scene (and half of the face on the photograph). Each photograph was presented in three different versions: without a shadow, with a shadow on the left half of the image, or with a shadow on the right half. Non-shadow regions had an average luminance of 31.6 cd/m^2, while shadow regions were an average of 7.56 cd/m^2. The stimuli were presented on a gray background (color code: 204/204/204; 81.1 cd/ m^2).

Design

Each participant went through 3 blocks of trials (4 practice and 44 experimental), one for each task (age, beauty and profession judgment). Within a block, each photograph was presented only once; half of the presented photographs contained female faces (the other half male faces); finally, one third of the presented photographs had a left shadow, another third had a right shadow and the last third had no shadow. The order of blocks was counter-balanced, and the order of the trials within each block was randomized for each participant.

Data Analysis

The Eyelink's parser, applying the standard 30 deg/sec and 8,000 deg^2/sec velocity and acceleration thresholds for cognitive research, was used to convert the horizontal and vertical recorded eye position into fixations and saccades. The fixations were then analyzed for the presentation duration of the face stimulus until the end of the last fixation before the participant pressed the spacebar to end the trial. For statistical comparisons, we used univariate analyses of variance (ANOVAs), applying a Greenhouse-Geisser correction where appropriate, and pairwise t-tests.

Results

Task

Participants performed three tasks and the differences between the tasks were tested with a repeated-measures ANOVA. The total viewing time differed significantly across tasks ($F= 18.60$, $p < 0.001$), with profession judgment talking the longest time and beauty judgment the shortest. Bonferroni corrected pairwise *t*-tests showed that this was due to significant differences between all three tasks (all *p*-values smaller than or equal to 0.001). The number of fixations was significantly different across tasks ($F = 39.82$, $p < 0.001$): most fixations were found for the profession judgments, and fewest for the beauty judgments. Pairwise t-tests showed that there were significant differences between each of the tasks (all *p*-values smaller than 0.001).

Shadow

To examine the influence of the shadows, three measures were compared across conditions with the shadow on the left, the shadow on the right, and images without shadows. If participants sample more often from the illuminated section of the image, it would be expected that this area of the image would be sampled earlier and more frequently than the shadow section.

First fixation: The first measure, indicating the proportion of first fixations towards the left section of the image, is plotted in Figures 1a across all three tasks. The first fixation is less often on the left section of the image when the shadow is on the left side and more often towards the left when the shadow is on the right (all data: $F_{2,40} = 55.03$, $p < 0.001$), suggesting that participants avoid starting their inspection of the part of the image in the shadow. There was no interaction between the task and the shadow position ($F = 0.68$, $p = 0.50$) and there was no main effect of the task ($F = 0.49$, $p = 0.55$) in a three by three ANOVA testing the effects of task and shadow location. This result suggests that participants would avoid shadow irrespective of the shadow region task.

Dwell time: The second measure considered is the overall dwell-time on the left and right side of the image across the different shadow conditions. Figure 1b shows that across the entire trial, participants' gaze direction is biased towards the side of the image not containing a shadow and a highly significant effect of shadow location on dwell time is found ($F_{2,40} = 86.25$, $p < 0.001$). The interaction between task and shadow location on dwell time does not reach significance in a three by three ANOVA ($F = 2.34$, $p = 0.094$).

Number of fixations: While dwell time suggested that the first fixation towards the section outside the shadow is not compensated by longer fixations towards the other side, this does not exclude the possibility of a compensation in terms of the number of fixations. Figure 1c shows a very similar pattern as for the other two measures considered. The number of fixations shows an almost identical pattern of results, with a significant effect of task ($F_{2,40} = 4.44$, $p < 0.018$) and a highly significant effect of shadow location ($F = 116.52$, $p < 0.001$).

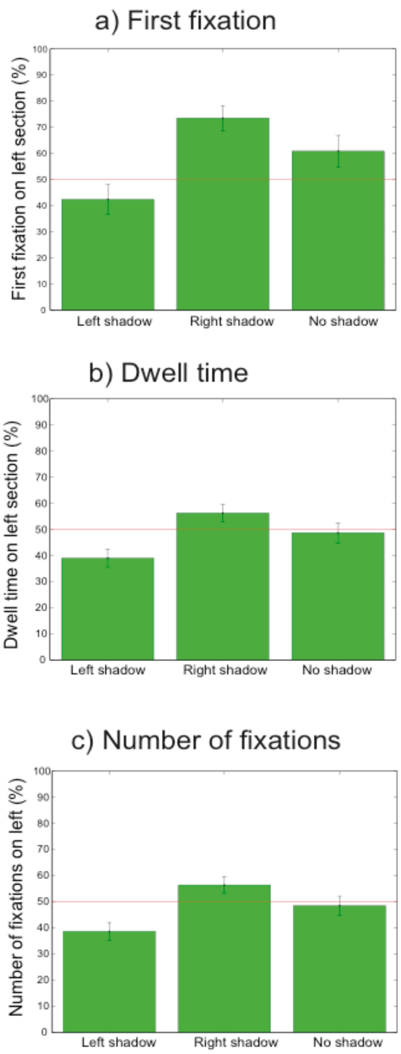

Figure 1: a) First fixation location for left shadow, right shadow and no-shadow conditions. b) Dwell-time on the left side of the image as a percentage of the overall dwell time on the image for the three shadow conditions. c) Number of fixations on the left of the image as a percentage of the overall number of fixations on the image. In all three plots, the error bars represent the standard error of the mean across participants and the horizontal red lines, the 50% point.

Discussion

Our results show that, by placing cast shadows in our images, we could influence participants' eye movements away from the shadowed region. This effect was apparent for all three measures (the first fixation, the overall dwell time, and the number of fixations) and it was independent of the task.

Our results are in line with previous observations that focused on tasks involving lightness perception (Toscani et al., 2013a, 2013b), studies of eye movements in natural scenes (Tatler et al., 2005) and assumptions made by saliency models (Itti & Koch, 2000).

Our results also make sense intuitively: regions that fall inside a shadow have a lower contrast, and therefore it may be beneficial to instead focus on sections of the image that do not contain a shadow, presumably because more information may be extracted from these regions. However, while participants' eye movement were significantly influenced by the presence of cast shadows, the influence of the shadows was small in magnitude, clearly showing that observers do not avoid darker regions all together.

In the present study, we focused on black and white images and on lightness. Future studies could examine the role of lightness in colored images, and determine whether similar direct influences of other color dimensions can be found.

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