Shading and shadowing on Canaletto's Piazza San Marco

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ABSTRACT

Whereas the 17th century painter Canaletto was a master in linear perspective of the architectural elements, he seems to have had considerable difficulty with linear perspective of shadows. A common trick to avoid shadow perspective problems is to set the (solar) illumination direction parallel to the projection screen. We investigated in one painting where Canaletto clearly used this trick, whether he followed this light direction choice consistently through in how he shades the persons. We approached this question with a perceptual experiment where we measured perceived light directions in isolated details of the paintings. Specifically, we controlled whether observers could only see the (cast) shadow, only shading or both. We found different trends in all three conditions. The results indicate that Canaletto probably used different shading than the parallel light direction would predict. We interpret the results as a form of artistic freedom that Canaletto used to shade the persons individually.

Keywords: Art and Perception, Illumination perception, Pictorial space, shadows and shading

1. INTRODUCTION

The Venetian painter Canaletto (1697-1768) is famous for his detailed city-views (vedute) of Venice and London, in particular his views of Piazza San Marco in Venice. There is ample evidence that Canaletto was striving for his paintings to appear as realistic as possible.[1,2] It is most likely that he went outdoors with a camera obscura to make detailed sketches incorporating marks of how shadows are projected on buildings (for an example, see Kemp[1]). Later on these sketches were integrated to form the basis of his paintings.

Although many paintings of Canaletto seem to be meticulously constructed, there are some unexpected 'errors' in his paintings. For example, we previously found a substantial sideways size gradient in the persons on the San Marco Square.[3] Furthermore, when analysing another painting of San Marco square, we found that Canaletto seems to have difficulty with two-point perspective, as we will shortly discuss below.

In the painting shown in figure 1, we traced some of the building and floor lines. In the right vanishing point, all lines converge neatly. However, in the left vanishing point convergence is poor. The floor lines belonging to the famous pavement pattern, do not meet at the horizon. Some difficulty may be expected because the pavement patterns are not orthogonal to the facade of the basilica, but that is no reason to not converge at some point on the horizon. Another interesting observation is that also the shadows of the flagpoles (indicated by the thick light grey lines) do not meet at the horizon. Note that the leftmost flagpole even does not cast a shadow.

When analysing the shadows in this painting in more detail, we see that the shadows cast by the persons on the square show hardly any perspectival consistency. On the left side of figure 2 we plotted the relative size of the persons, which reveals that the vertical size gradient is painted rather well. To get a better idea of how the shadows should be, we estimated the perspectival position of the sun. It is difficult (if not impossible) to accurately estimate this position, but it should be noted that the accuracy does not influence the argument we are trying to make here. In the middle of figure 2 we show this reconstruction, and on the right side we show the painted shadows together with the reconstructed shadows. As can be seen, the painted shadows do not converge, although some of them are consistent with modelled shadows (mostly on the right side of the painting).

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Figure 1. View of the Church and the Doges Palace from the Procuratie Vecchie (1742). National Gallery of Art, Washingon. Blue lines follow architectural lines, medium grey lines follow shadows of flagpoles and the black lines indicate the persons and their shadows.

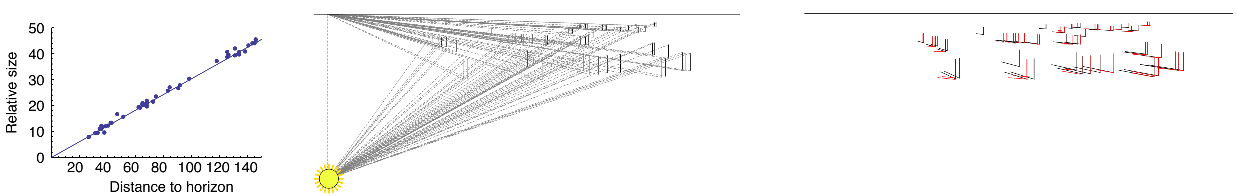

Figure 2. Left: size gradient of persons. The trend is linear and intesects the origin (objects are infinitely small at the horizon). This indicates that Canaletto followed the rules of perspective very well with respect to the sizes of the persons. Middle: a shadow reconstruction, where we roughly estimated the position of the sun. Right: the difference between the painted shadows (red) and the modelled shadows (black).

Painting shadows cast by the sun is in theory not more difficult than painting the environment in perspective. Shadows that are cast by the sun on a flat horizontal floor are in reality parallel to each other. Rules of linear perspective dictate that parallel lines on the ground floor should vanish in a point on the horizon: the horizon is effectively the collection of all vanishing points of lines on the ground floor. There is one important exception to this perspective rule, and that is the case when lines are parallel to the projection plane, i.e. the painting. Horizontal lines (in the painting) do not converge but maintain to be horizontal, and therefore parallel to other horizontal lines.

On the one hand, one may presume that Canaletto failed to render the cast shadows correctly because he simply was unaware of the underlying shadow perspective rules. But on the other hand, Canaletto (and many other painters) seem to be aware of the exception concerning horizontal lines staying invariantly horizontal under perspective transformations. The painting shown in figure 1 is a relative exception with respect to his other paintings: in most of them he makes use of the horizontal shadows trick and thus avoids the necessary convergence on the horizon.

A representative example is shown in figure 3, which is a cropped version of the original (we only show the lower part here). As can be clearly seen, the sun light comes from the right-hand side, casting shadows to the left-hand side of the persons. Shadows are not the only pictorial ingredients that echo the interaction of a scene with light. Another ingredient that is much more prominently present throughout art history is shading: the reflection of light from a surface. Shading is clearly used by Canaletto, and we were interested in how congruent the shading is with the (cast) shadowing. Applying a parallel light direction for rendering the shading would result in a body shadow (which we regard to be part of the shading process) that approximately covers half of the visible surface. This may not be preferred, and an initial inspection of some of Canaletto's paintings suggested to us that he indeed did not use a congruent shading direction. Our hypothesis is thus that Canaletto used the parallel shadow trick to avoid perspective problems, but takes his freedom when shading the individual persons.

To investigate this issue, we designed an experiment with which we quantify the apparent light direction, i.e. the light direction as perceived by observers. We cannot analyse the 'real' light directions, because reality does in this case not exist. Canaletto creates a pictorial world, and the only aspect we can address is what is the resulting percept. From the perception literature, it is known that in general, humans are quite insensitive to shadow discrepancies.[4] This may be the reason why this issue has up to now not received much attention in the perceptual analysis of paintings: it is simply hard to notice. We developed a paradigm through which we can quantify the relative contributions of shading and (cast) shadowing on the perception of illumination direction. In a computer experiment, observers were shown cut-outs of persons under three conditions: shading-only, shadow-only and shading and shadow. Observers had to match the illumination direction of these stimuli with the direction on a rendered sphere which could be manipulated.

2. METHOD

2.1 Observers

Nine observers participated in this experiment, seven students and the two authors. All participants had some experience with light direction estimation (either through graduate research or by following a course about light design). The two authors were the only observers who were not naive with respect to the purpose of the experiment. However, they both participated in the shadow-only condition which is the most straight forward condition. We believe that it is close to impossible to cognitively penetrate perception in this condition.

2.2 Stimulus

We choose a painting from Canaletto which is rendered very consistently with the parallel shadow style as discussed in the introduction: Piazza San Marco (1742-1746). At the moment of writing, this painting can be explored virtually at the Google Art Project website, or in real life at the Art Gallery of NSW in Sydney, Australia. In figure 3 we show the lower part of the painting with red polygons indicating the subjects of interest. Below the painting, the cut-outs are shown of the eight stimuli.

Figure 3. Piazza San Marco (1742-1746), Art Gallery of NSW (Sydney). Only the lower half of the painting is shown. Red outlined are the persons that were used as stimuli, cut-outs are shown below.

2.3 Procedure

We explored three different conditions: shadow-only, shading-only and shadow and shading. In the shadow-only condition we showed the original shadow, but the cut-out of the person was rendered homogeneously black, like a silhouette. The stimulus was shown on a homogeneously coloured background, using the average colour we sampled around the original shadow. In case of the shading-only condition, the shadow was simply omitted, and the person was shown normally (not silhouetted). In the shadow and shading condition we showed the full cut-out of the persons and the shadows. Each observers was only presented with one of these conditions, with the exception of one observer who was shown the shading-only and the shadowing-only condition. All software was written with PsychToolbox.[5,6]

Figure 4. Three screenshots of the three conditions. The background colour for each stimulus was based on the average colour around the shadow (in screenshots shown here, all stimuli are the same person, hence the same colour). The illumination direction on the two white spheres could be controlled on a trackpad by the participant.

The stimuli (persons and shadows) were positioned in between two light direction probes. The observer was instructed to adjust the light direction on these probes to match the illumination direction on the stimuli. Observers were aware that the sun was the main light source, i.e. a collimated light field. Furthermore, they were told that the light probes were rendered in orthographic projection.

The eight stimuli shown in figure 3 were not the only stimuli the observers were presented with, but in the paper we will only discuss these eight stimuli, i.e. only one painting. In total, 25 stimuli were shown, repeated three times. The experiment took approximately 20 minutes to complete.

2.4 RESULTS

The original parametrisation was in slant (angle with picture normal) and tilt (angle *in* the picture). However, for our visualisations, we used two projections of the light vectors as is illustrated on the left-hand side in figure 5: the xy-plane (picture plane) and xz-plane ('ground' plane). To reveal main trends in the data we calculated circular histograms (the red dotted lines in figure 5). For these histograms we used 100 bins (i.e. 3.6° per bin) and smoothed using a moving average (box convolution) of 3 bins. Furthermore, we transformed these histogram values similar to a gamma correction (max value was first scaled to one), to increase 'contrast', i.e. make smaller trends visible.

The first thing that immediately becomes clear upon viewing figure 5 is that the shadow-only data is much less dispersed than the other conditions. For this condition, the xy projection shows a very consistent direction of about 220°. We checked this value with the eight cut-outs as shown in figure 3. In this image the shadows appear to be longer than the humans. However, we drew a line from the end of the cast shadow to the appropriate tangent point on the head or hat, and found an average of 223°, values ranged between 218° to 228°. For this short analysis, we omitted the second stimulus in figure 3 because we were confused about that shadowing. Continuing and finalising our analysis of the shadow-only condition, we see that the top view (xz-plane) shows that the light direction is neatly distributed around 180°, as would be expected from figure 3.

Next is the shading-only condition. In the xy-plane the mean direction now shifted to 215° and the spread increases dramatically with respect to the shadow-only condition. It should also noted that the majority of the settings is below the 225° direction we found in the shadow-only direction, implying that the sun is estimated to be lower on the horizon in the shading-only condition. The xz-plane shows a large bias with respect to the 180° direction: the majority is in the upper quadrant (between 180° and 90°). Furthermore, there seem to be two modes in the circular histogram, showing a local minimum at 180°.

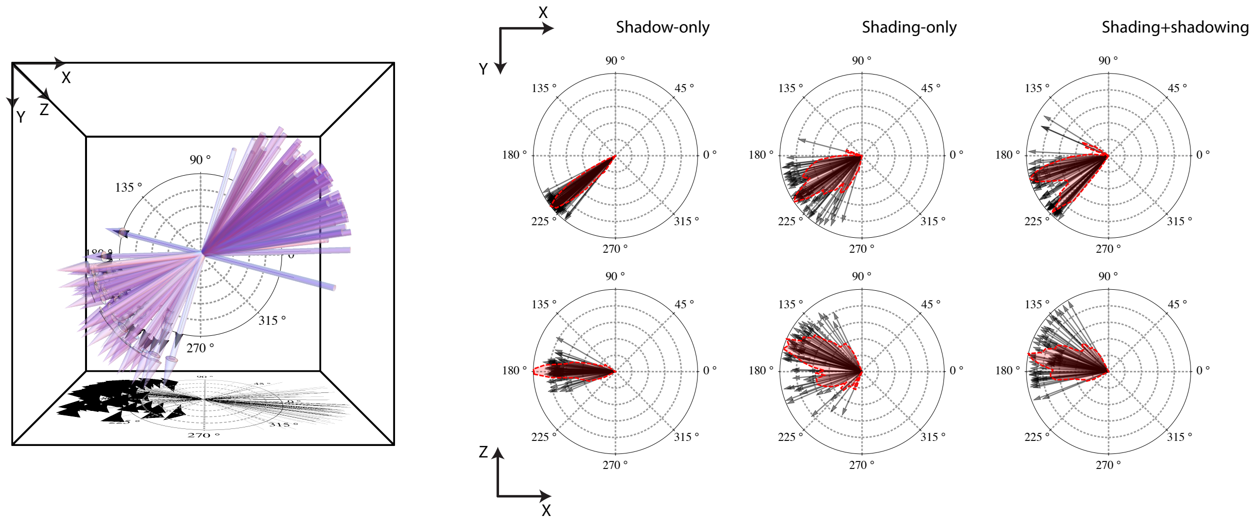

Figure 5. Left: an example of the light direction data (in this case the shading-only condition) and how the two projection planes are defined. In the upper left corned the three axes directions are shown. Middle/right: polar plots of two projection planes. The arrows show the raw data, the red line denotes a circular histogram.

Lastly, the condition in which shading and shadowing are combined reveals trends that are dissimilar to either of the isolated conditions. In the xy-plane we see that there are clearly two modes. Closer inspection of the data revealed that this trend is likely due to differential settings between observers (all plots show combined data of three observers). Some observers seem to rely heavily on the shadowing information while others more on shading. This was also noted by one of these participants who commented that the two cues did not always seem coherent. In these cases, she said, she would focus on the shading information. Furthermore, the xz-plane projection shows a trend that appears to be a cue combination because the dispersion found in the shading-only condition is reduced in the combined condition. The mean direction seems to converge to the 180° direction we previously found in the shadow-only condition.

2.5 DISCUSSION

We have performed an experiment in which we disentangled the contributions of shading and shadowing on light direction perception. The motivation behind this experiment originates from the art historical observation that Canaletto very often uses parallel shadow directions, as most of his peers. We were interested whether he would consistently follow this light direction choice in his rendering of the shading. While the motivation originates from Canaletto, the scope of the study is broader since it is concerned with how sensitive human observers are to discrepancies between shading and shadowing.

Most studies on illumination inconsistencies reveal that the human is remarkably insensitive to them.[4,7] An actual shadow projection can easily be substituted by simply copying the outline of the shadow casting body, without any perceptual repercussion.[4] Although cast shadows give effective 3D position information,[8] differences between shading and shadowing are not very well noticed.[9] Furthermore, we showed previously[10] that light direction estimation of cast shadows do not follow the rules of linear perspective, much like the errors Canaletto made in the painting in figure 1.

To our knowledge, not much knowledge exists in how the human integrates shadow and shading information when it comes to light direction estimation. In our experiments we did not use the globular shapes as stimuli, that are often used in visual psychophysics. Instead, we used upright standing persons. The global shape of these objects is cylindrical, which should be taken into account when interpreting the data. For a shaded (no cast shadows) upright cylinder, the 'in plane' light direction, i.e. the height of the sun, is a priori more ambiguous than the 'out of plane' direction, i.e. the compass direction of the sun. This is the reason why we split the data presentation in the xy and xz plane. The xy plane data of the shading-only condition are more dispersed than the shadow-only condition but this could be due to the above mentioned ambiguity, instead of a rendering inconsistency. One would expect that in the complete stimulus presentation (shading and shadowing) the ambiguity vanished much like the shadow-only condition. However, this is clearly not the case. The shadow and shading condition does show a marked difference with respect to the shading-only condition because of the bimodally shaped histogram. As we already mentioned in the results section, the reason behind this bimodal distribution with maxima at 195° and 225° may be that different observers are sensitive for different cues. In other words, the weighting of the cues may be different for different observers. There is a clear suggestion that cues are not combined optimally. This may be happening because the human *visual system* does not combine these cues optimally, or because *Canaletto* does not combine these cues properly in his paintings. This cue conflict situation obviously does not exist in reality. Therefore, it may be worthwhile to investigate how humans integrate information of shading and shadowing in real (i.e. photographic) conditions.

In the xz-plane, one would expect less ambiguity to the shading-only condition, because of the global cylindrical shape of the persons. Overall, the variance seems equal to that in the xy plane. However, it may also be the case that the individual stimuli are not ambiguous at all, but that the variation *between* the stimuli causes the variance in the observers' data. Due to the low amount of observers we have tested for each condition, this hypothesis can at the moment not be investigated. However, if indeed the variation in the shading-only condition is due to individual variations of shading in the eight figures, then Canaletto took much freedom and indeed rendered the shading inconsistently with the shadowing. It would mean that depending on the person, Canaletto uses a different illumination direction to alter the appearance of the persons on San Marco on an individual basis. The reasons behind this (hypothetical) individual light treatment may have art historical roots that are unknown to us.

ACKNOWLEDGMENTS

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