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Subject review

The Role of Light and Shadow in the Perception of Photographs

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Abstract: The photographer's awareness of the light in the scene is the key to good exposure, whether it is technically correct or an expression of creativity. The article deals with the role of light and its absence, shadow, in the field of photography. Several studies from history and the present are presented, linking the perception of light and its shadows from philosophical, artistic and technological points of view, illustrating the vastness and applicability of this field of research. Summarized studies and an eye tracking analysis of shadow perception support the author's claims about the role of light and shadow in the perception of Henri Cartier-Bresson's photographs. It is shown how shadows can reveal more to the viewer about the space surrounding the observed scene, function as individual objects, or even be used creatively to enhance the detection of focus within a photograph.

Keywords: eyetracking; light; perception; photography; shadow

1 INTRODUCTION

Kuhn [1] notes in her essays that "photography seems to record rather than interpret a piece of the world in front of the camera." Although the content of a photograph can be interpreted in its own way, it still reflects the current state and thus the same pattern of light to our eye that the object itself would normally emit [2]. This description of the function of the photograph can be traced back in time even further, as psychologist [3] described it as a "delimited physical surface processed in such a way that it reflects or transmits a sheaf of light rays to a given point that is the same as the sheaf of light rays from the original to that point." Similar statements are found in art, where the contents of a painting should be seen through the frame as through a window [4].

This is only possible by projecting light onto a surface, using the same principle as the image is formed on the retina of the eye. Light emitted or reflected from an object is collected by a series of optical systems and projected onto the image plane [5]. This projection from three-dimensional space onto a two-dimensional plane reduces dimensionality, or in other words, it flattens the geometry of an object. This type of parallel projection preserves relative dimensions and therefore produces an accurate view of the object [6] However, the sense of three-dimensionality must be created by the viewer.

Constructivist theory states that we associate a three-dimensional visual input with something tangible and therefore associate the projected objects we see with physical objects we already know [2]. Appropriate illumination of the observed scene allows us to better define edges and thus perceive the objects depicted [7]. In addition, the shape of an object's shadow can tell us more about the object itself and the surrounding space [8, 9]. [10] describes the interaction of light with observed surfaces and defines three lighting patterns - illumination, shadow, and highlight pattern - each of which influences our perception of the surface. Without shadows, their texture, gradation, and variety, the viewed image would be perceived as lifeless [11].

2 DESCRIBING LIGHT AND ITS SOURCES

Light is formed with electromagnetic waves, oscillating electric and magnetic fields perpendicular to its direction. Waves with the same wavelengths produce light that we perceive as a single colour and is therefore called monochromatic light. However, many light sources emit light with different wavelengths. Light transports energy due to its electric and magnetic fields, although the latter do not affect matter as much as the electric fields. When the light rays encounter a matter on their way, they can either be reflected, partially reflected, absorbed, or even scattered in it. When scattering occurs, it can cause light to be reflected in various ways by heterogeneous particles in the matter. These phenomena are called diffuse light reflection, volume light reflection, and remission of light [12, 13].

Each light source can be described by its luminous intensity, which indicates how much luminous flux, or simply power, is distributed by the light source to the space of a certain spatial angle. Depending on the latter, we divide them into point, line and area light sources. When they emit light uniformly in all directions, they are called isotropic, an example of which is the sun. A laser, on the other hand, emits light non-uniformly and is therefore called anisotropic [12-14].

[15] describe light in the field of photography using four descriptors: amount, colour, contrast, and direction. The differences are described in this section and illustrated with 3D renderings created by the authors using set.a.light 3D V2.5 software (Elixxier, Germany).

Amount simply describes the amount of light illuminating the scene (Fig. 1a and Fig. 1b). The colour is a consequence of the wavelength of the visible light on the set, which reflects different portions of the red, green, and blue visible spectrum and creates a cool, neutral, or warm impression of the image (Fig. 1c and Fig. 1d). The correlated colour temperature (CCT) of light sources is expressed in Kelvin and tells the user whether the emitted light appears more yellow or more blue. Colour rendering index (CRI) describes how well colours are reproduced under a particular illumination compared to a standard light source [16]. Contrast is used to describe the differences in brightness between the lightest and darkest parts of the scene. According to [17], a high-contrast image is one with a ratio of the lightest and darkest elements of 32:1, while a low-contrast image has a ratio of 16:1. Contrast can also be described with brightness range or dynamic range, both of which describe the level of luminance range of a scene, as seen in Fig. 1a and Fig 1b, but are more commonly used to refer to the capabilities of the camera's rendering system. The direction of light can be from the front, from the side, from behind, reflected, or overcast. Each of these directions leaves its mark on the photo, as the quality of colour reproduction and the amount of shadows depend on it (Fig. 2).

[17] replaces the descriptor of quantity used by [15] with intensity and further divides it into reflectance and fall-off. Reflectance is important because the camera's exposure meter measures the amount of light reflected from the subject. Depending on the colour, texture, and angle of the light, the subject's surface reflects different amounts of light, which is called subject reflectance. Bright and reflective surfaces reflect more light, changing the light setting of the scene (Fig. 2c and Fig. 2c). Depending on the light source, we can experience the fall-off effect. It is a consequence of the inverse square law, which states that only a quarter of the light reaches the subject when we move it twice the distance away from the light source (Fig. 3a)and Fig. 3b). This applies not only to light sources, but also to reflective objects.

Another descriptor of [17] is the quality of the light. The division into hard and soft describes the hardness of the light and thus the amount of shadows and their defined edges. For example, hard quality light comes from the sun or an open flash and produces directional shadows that are dark and have well-defined edges. Soft light, on the other hand, produces hardly any shadows and dulls the colours and contrast, as shown in Fig. 3c and Fig. 3d [18]. The quality of the light is a consequence of the size of the light source relative to the subject. If the light source is larger than the subject, the emitted light will appear softer, and vice versa. Thus, a hard light can be softened by bringing it closer to the subject.

(a) (b) (c) (d)

Figure 1 The amount of light on the scene conditions the contrast of an image: (a) less light, (b) more light, while colour temperature sets the mood: (c) warm lighting and (d) cold lighting

(a) (b) (c) (d)

Figure 2 Comparison of (a) front lighting, (b) side lighting, (c) back lighting and (d) back lighting with added white reflective surface in front of the subject

(a) (b) (c) (d)

Figure 3 If we move the light source from its (a) original position (b) away from the subject, we can experience the fall-off effect. Comparison of (c) soft and (d) hard light

3 SHADOW AND ITS FORM

Depending on the shape, size, quantity, and distance of the light source from the object, the shadow it casts varies. The complexity of the shadow also depends on the surface on which it is cast. The simplest projection of the shadow is on flat surfaces, while highly complex geometries are seen on curved surfaces [14].

The shadow is a result of light being blocked by the occluder. Fig. 4a and Fig. 4b show how the light source affects the type of shadow cast. With an isotropic point light source, the shadow cast is uniform, with distinct boundaries of the projection as well as on the object. If you illuminate the occluder with a non-point light source, the rays coming from it will have a different direction at each position of the light source. Therefore, the projection is also more complicated and, in some ways, even resembles the illumination with multiple light sources. Consequently, we can divide the cast shadow into an umbra and a penumbra. The latter describes the parts of the shadow that are illuminated with part of the emitted light rays (Fig. 4b). These areas appear brighter, but the boundary between umbra and penumbra is often difficult to define [12-14]. The penumbra can be caused not only by a non-point light source, but also by the diffraction of light rays by the occlude [19].

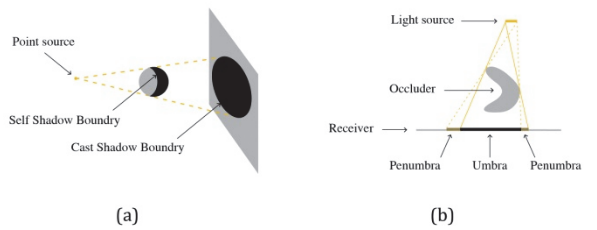

Figure 4 (a) Self-shadow and a cast shadow of a sphere lit with a point source and projected on a flat surface [14]. (b) Describing shadows with light source, occluder, receiver, shadow, umbra and penumbras [12]

As described in the previous sections, shadows can be hard or soft depending on the quality of light. In soft light, the outer edges of the shadow appear softer, more blurred. The same effect is achieved when the occluder is further away from the surface of the cast shadow. This can be easily observed when we look at our own shadow on the floor while standing. It dissipates toward the upper part of the body [12].

Shadow detection methods are of interest to many researchers, especially in the field of computer visual recognition [19, 20]. Because their presence in an image can result in some loss of information, researchers are developing methods for better edge detection, object tracking, and overall scene understanding in machines that capture surveillance footage [9]. Although shadows are undesirable in this profession, they are essential for achieving photorealism in 3D renderings [21]. To achieve this, certain guidelines should be followed. [22] established ten principles that affect the photorealism of renderings, and at least eight of them should be followed: (1) clutter and chaos, (2) personality and expectations, (3) believability, (4) surface texture, (5) specularity, (6) aging-dirt, dust, and rot, (7) flaws, tears, and cracks, (8) rounded edges, (9) object material depth, and (10) radiosity. [23] redefines these principles and asserts that it is important which eight of Fleming's ten principles one should follow. He groups Fleming's Specularity and Radiosity into the category of Global Illumination and claims that this category is key to achieving photorealistic renderings because even accurately rendered objects will not be perceived realistically without appropriate lighting and resulting shadows.

4 LIGHTING A PHOTOGRAPHIC SCENE

Light can be natural or artificial, the latter being household lamps, flash, headlights, televisions, halogen lamps, firelight, etc. Each of these lights has its own characteristics related to either colour temperature, intensity, or quality. Artificial lighting can also be divided into continuous and non-continuous lighting, the latter emitted by flashing devices, also called strobes [18, 24]. The original light emitted from a light source can be reshaped according to the photographer's preferences. The direction, focus, and quality of the light can be changed using light modifiers, also called shapers [18]. [24] introduces definitions for a variety of objects that are capable of transforming light. However, he claims that it is impossible to accurately represent all shapers available on the market and their effects on the original lighting.

Several sources [24-26] state that natural light has its own meaning and character and contains more information about the current scene which should not be discounted. Moreover, in portrait photography, it is important that the subject is relaxed, which is much easier to achieve with less surrounding lighting equipment. Natural light, also called ambient or available light, allows the photographer to more accurately predict the outcome because the relationship between highlights and shadows can be seen in advance [18].

When using artificial light, it is important to be aware of its capabilities. A light source can already provide a number of possibilities. First, it can be used as a hard light that creates sharp shadows. If you position the light source so that it faces a white wall, the light from the wall will reflect onto the subject in front of it, illuminating it with a softer light, as shown in Fig. 3c and Fig. 3d. As you move the light source away from the wall, this altered light source, i.e., the illuminated wall, becomes a larger light source relative to the subject, making the illumination appear even softer and more uniform. With careful positioning of the direct light source at a 45° angle and some basic modifiers like a softbox or umbrella, you can create the Rembrandt light that casts the shadow of the nose in a particular way, forming an illuminated triangle on the adjacent cheek. If you reduce the angle of the light source with respect to the camera to 30°, a loop light is created that also partially illuminates the distant part of the face. A short light illuminates only the front part of the face, but slightly less than the ear. It can be produced by pointing the light source at the subject at a 90° angle. All these single-point source lighting set ups create drama because of their higher contrast ratio (Fig. 5). When positioned at an angle, they bring out textures, reveal shapes, and add depth to images.

When you add light sources, they all have different functions. The first light source is the main light, also known as key light, which forms the base of the scene.

Further on, you may add a second light source, known as a fill light. Its function is to lighten the shadows and illuminate the part that the key light cannot reach. Its intensity is lower than that of the key light, and the ratio between them varies from set up to set up. Adding a third light source can add a distinctive feature to the photo (Fig. 6). It is usually placed in the background and has different names depending on its function: back light, rim light or hair light. Depending on its use, it can be very robust or subtle. If you are shooting from darker areas toward brighter ones, that would be back light. For example, taking photos from a cave or towards the sun, where the subject is often completely in shadow. The rim light occurs when the third light source is much brighter than the key light, wrapping the light around the subject from behind so that it glows. In portrait photography, hair light creates highlights in the hair that make the head stand out from the background [18, 27].

One should also be aware of the size of the light source. It has already been mentioned that depending on the size of the light in relation to the subject, the edges of the shadows will appear softer or harder. If it is not possible to use a large light source, you can modify it with diffusing screens, umbrellas, bounce cards, etc. to increase the effective size of the emitted light.

If you do not have enough light sources, it does not mean you cannot set up three-point lighting. Various materials can be used to reflect light and serve as another light source. If the photographer is creative, he or she can find even more solutions, such as blocking the middle part of a larger light source, splitting it in half and creating a two-point lighting effect. In doing so, the nature of the materials allows the light to be shaped so that it becomes more diffuse, more colourful, or more focused on the subject [28].

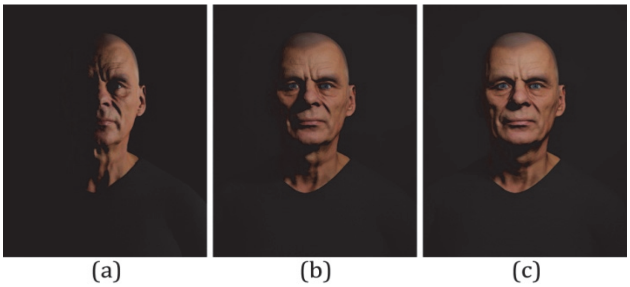

Figure 5 (a) Short light, (b) Rembrandt triangle and (c) loop light

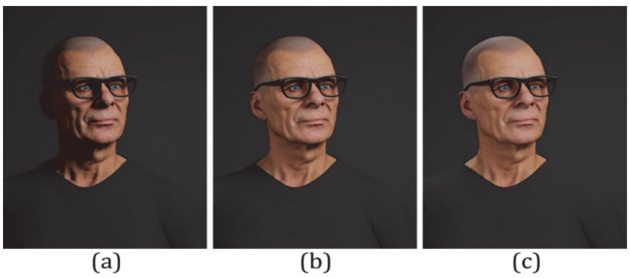

Figure 6 (a) Key light, (b) added fill light and (c) an addition of back light

5 THE ROLE OF LIGHT

Light can be considered complex because many of its properties affect the information it reproduces. The combination of knowledge, skill, and craftsmanship allows the photographer to fully understand it and use it as an invaluable communication tool [17]. The use of appropriate lighting is the main feature to make amazing and memorable images [15]. [29], on the other hand, argues that there is no perfect lighting, only a perfect response from the photographer to achieve a perfect exposure. With the right exposure, the illusion of depth and lighting with an appropriate mood and feel, a perfect image can be achieved [30].

An exposure can be understood in different ways. Since the early days of photography, it has stood for a recorded image, but nowadays it is more commonly used to express the amount and behaviour of light falling on the imaging sensor. The latter is the one that should be correct. [29] goes on to state that for any scene photographed, there are at least six possible combinations of settings that affect exposure (aperture, shutter speed, ISO sensitivity) and result in the correct exposure. But only one of the combinations of settings will give the creatively correct exposure, since the desired result can only be achieved either at a particular aperture setting with the adjustment of the shutter speed or vice versa, both conditioned by the ISO sensitivity. The creatively correct exposure is however a subject of an opinion because it is the photographer's tool to depict a certain mood by making images lighter or darker, overexposed, or underexposed [17].

The illusion of depth is necessary in a photograph because it is deprived of three-dimensionality by the projection of the image onto a flat surface. Depth in a photograph can be perceived on behalf of multiple indicators. The first is the occlusion shape mentioned by [31], which represents the object distorted in perspective. This can only be detected if one is already familiar with the object depicted, confirming the constructivist theory mentioned earlier. The illusion of depth can also be created by colour, differences in brightness, and the range of focus [32, 33]. Depending on the aperture chosen, photographic lens, and distance of the camera from the subject, the photographer can control the range of focus in the image and suggest the depth of an observed two-dimensional space [34]. When photographing with a greater depth of field, the sense of space can also be suggested by shadows [15]. Their position, value, texture, and shape can describe the environment and thus give an impression of space. Since they are a consequence of lighting, they can provide even more information about the space outside the camera frame to a trained eye [35].

If you subtract the chromatic component of the colours, only grey spots remain. If you arrange them from the lightest to the darkest, you get a scale that can be divided into groups with distinctive psychological effects. [36] explains four categories of behavioural states associated with shades of grey. The first category includes shades of grey with a grey value of 0 - 28%, which represent positive feelings, while every other higher gradation of grey represents negativity, which slowly progresses from disagreement to anger, sadness, revenge, and death in the last, fourth category. He suggests that this kind of visual linguistics is key to visual perception, especially in photography where black and white representations are still common even in the digital age. This perception of brightness levels and their influence on mood are well described in art theory, where combinations of brightness levels are grouped and named with musical metaphors such as high, middle, and low major or minor. Often this way of describing tonal values is called "valeur," which comes from the French word for value [37].

Painters have used different lighting positions and colours to create moods in their works [38]. The same approach can be found in other arts, such as architecture, graphic design, video production, and photography [30, 32, 39, 40]. [41] suggests that each colour can have a positive and a negative effect on the viewer. His interpretation of each colour is shown in Tab. 1.

Table 1 Range of colours with proposed positive and negative effect on viewer's mood [41]

Colour	Positive Effect	Negative Effect
Red	Power, Strength, Warmth	Offensive, Anxiety, Pain
Blue	Cool, Logic, Efficiency	Cold, Detached, Stoic
Yellow	Optimistic, Out Going, Creative	Fear, Fragility, Irrational
Green	Unity. Peace, Refreshment	Disgust, Bland, Stagnant
Purple	Spirituality, Truth, Bliss	Suppression, Inferiority, Corruption
Orange	Comfort, Food, Passion	Frustration, Adolescent, Jest
Pink	Tranquillity, Warmth, Feminine	Inhibition, Emasculation, Weakness
Grey	Compromise, Stable, Relief	Stoic, Quiet, Depression
White	Hygiene, Sterile, Simple	Sterility, Cold, Highbrow

6 THE ROLE OF SHADOW

Kaufmann [42] describes how shadow rendering became an integral part of painting in the 16th century and was studied along with perspective. Painters executed their art at the same time of day and under the same lighting conditions to preserve the visual mark of the painting. Shadows change with lighting conditions, becoming darker, lighter, sharper, softer, longer, shorter, which affects the viewer's attitude towards it [43]. A shadow can be looked at, or looked through, depending on the differences in the perception of the brightness constancy of a painting.

However, our perception of shadows is still a relatively unexplored area, or rather, there are no definitive conclusions. [28] state that a hard shadow is perceived as more visible than a soft shadow, so this imaginative tonal variation is the reason for the perception of a greater depth illusion. [44] describe several studies that address the hypothesis that we immediately recognize a particular area in a static image as a shadow, from which we extract information about the scene in general, but then focus only on the object. Minor errors in shadow projections are often not even noticed once past the recognition point. Since we live in a three-dimensional world, shadows are an everyday phenomenon. Nevertheless, not everyone is able to understand and visualize a 3D space in one plane. In addition to the difficulty of recognizing the boundaries of shadows, it is possible that the imperfections of the shadow are overlooked for a combination of these reasons. Failure to recognize the depicted shape could also affect the understanding of the actual object and its shadow, as it is well established that the representation of the object shape stored in our memory includes the object's shadow, which is also implied by the constructivist theory mentioned earlier [45].

On the contrary, in animations, videos and movies, shadows can attract our attention by their movement [46]. An interesting aspect is described when we do not see the object, but only its shadow. A moving shadow can tell us that something is approaching and is a harbinger that gives us information about what is about to happen. A shadow that overcomes us, or more specifically our point of view, makes us feel like we have no power. Although this happens in a moving environment, it can also be applied to a static environment.

7 PERCEPTION OF SHADOWS IN PHOTOGRAPHY

An excellent example of the use of shadows and their treatment as part of composition is the work of Cartier-Bresson. He himself says that "a composition is the result of a simultaneous coalition, the organic coordination of elements seen by the eye," while the balance between light and shadow in a photograph must be constantly controlled and the contrast ratio perceived by the naked eye matched [47]. The role of light and shadow in photography is often addressed in this way and their importance described, while we could not find any literature in which these phenomena were measured.

In this section, we examine human perception of shadows in a selection of Cartier-Bresson's photographs using two methods. First, we conducted a descriptive photographic analysis based on our personal experiences as photographers, instructors in the field of visual studies, and subjective perceptions of the content of the images. Second, we conducted an experiment on the same photographs using the eyetracking method [48], which provided us with quantitative information about shadow perception on the same images. Finally, we related the results of both methods and drew conclusions.

7.1 Descriptive Photographic Analysis

In Fig. 7, the strong contrast leads us to perceive the shadows as individual objects, adding dynamics to the photograph through their scattering. A closer look gives us more texture and information, and only then do we realize that we are looking at windows. The slightly lower contrast in Fig. 8 allows us to perceive the shadows as shadows, even though they are separated from their occluder. This important feature points to an empty space between the floor and the dancers that creates movement and provides the viewer with information that is not integrated into the static image by default.

Figure 7 Henri Cartier-Bresson. SPAIN. Madrid. 1933

Figure 8 Henri Cartier-Bresson. CHINA. The "Great Leap Forward". Beijing. 1958. October 1st

When the connection of the shadow to its occluder is not seen, an impression of the surrounding space is created, as seen in Fig. 9 to Fig. 11. In Fig. 9, the shadows of the linear roofing create a repetition and, with their diagonality, give a different dynamic to the otherwise vertical elements. The light coming in between the roofing lights up the subjects' faces and brings them to the foreground.

Figure 9 Henri Cartier-Bresson. CHINA. Beijing. December 1948. Final days of the Kuomintang. A peasant, whose market has closed down and came to Beijing to sell his vegetables, sits to eat his provisions. A shopkeeper resigns to have nothing more to sell in his store

Figure 10 Henri Cartier-Bresson: INDIA. Gujarat. Ahmedabad. 1966. In the old town

In Fig. 10, a tired worker dreams of a better life. This is, of course, a statement in terms of interpretation, but it shows the power of composition and shadows acting as objects. Not only can shadows act as objects, but their absence can create a negative form of highlights and bring another subject to the foreground, as seen in Fig. 11.

Figure 11 Henri Cartier-Bresson. ITALY. Rome. 1959

Figure 12 Henri Cartier-Bresson. »Our cat Ulysses and Martine's Shadow«. 1989

Figure 13 Henri Cartier-Bresson. MEXICO. State of Oaxaca. Oaxaca. 1963

As described in one of the previous sections, shadows can indicate something that could or will happen. In Fig. 12, the woman's shadow is gazing towards the sunbathing cat. One can assume that her hand will soon reach into the frame and pet the cat. Similarly, in Fig. 13, change is imminent as a woman walks down the stairs to meet her colleague.

7.2 Quantitative Method
7.2.1 Methodology

Quantitative analysis was performed using the Tobii X120 eye tracker, set to 120 Hz mode, and Tobii Pro Lab software. A 25-inch screen with a resolution of 2560 × 1140 pixels was used. Subjects were located 60 ± 5 cm from the front of the screen and the eye tracker, with their eyes level with the centre of the screen.

We tested 31 volunteers aged 20 to 25 years. 26% of the subjects were male and 74% were female, with normal or corrected vision. Subjects rated their photographic knowledge and skills on a scale of 1 to 5, ranging from 1 to 3, with 1 being nonexistent and 5 being professional.

Each of the seven photos tested was displayed in the centre of the screen at 1000 pixels across the long edge. Each photo was displayed for 8 seconds to ensure a high level of quality measurement [49], with 1 second blank screen pauses. The background for the images and blank screens was set to dark grey to minimise the screen brightness load on the eyes.

For analysis of the gaze data, we defined areas of interest (AOIs). Each image was divided into sections, AOIs, regarding one of the variables: (1) a subject or a group of subjects, (2) shadow of a subject, (3) silhouette of a subject, (4) shadowed area, (5) non-shadowed area. The number of fixations, duration of fixations, and other relevant data within these AOIs were analysed using the Tobii I-VT (Fixation) filter. The quantitative results are presented along with heatmaps of the gaze data for better understanding of the results.

7.2.2 Results

In Fig. 14, the first AOI was defined as a polygon over the subjects' area, while the second AOI is a polygon containing the windows. From Fig. 14, it can be seen that the participants were more interested in the areas containing human figures, which is confirmed with averaged fixation count of 12 (standard deviation SD = 4) for the first area and 5 (SD = 2) for the second area. The same is also confirmed with time to first fixation, as the first AOI was observed on average 2.52 ms (SD = 1.73 ms) before the second AOI. However, average fixation duration was 0.28 ms (SD = 0.08 ms) for the first region and 0.27 ms (SD = 0.11 ms) for the second region, showing that the relevance of the areas was the same for the observers.

In Fig. 15, a similar trend can be seen that people's faces receive more attention than other areas. However, it is clear that the adjacent shadow of an observed person also receives attention, especially in the central area of the image where both are fully visible. Each person in the image was defined as an individual AOI, as was their shadow. The average fixation count on the central person was 2 (SD = 2), and for her shadow was also 2 (SD = 1). The average fixation duration on the person was 0.34 ms (SD = 0.20 ms), on the shadow 0.26 ms (SD = 0.21 ms). The longer fixation duration on the person may explain the larger deviation in AOI visits, as it is possible that participants returned to the shadow several times but observed the person longer.

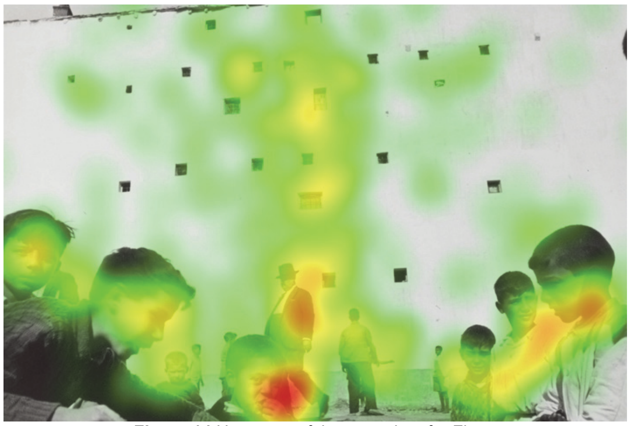

Figure 14 Heat map of the gaze data for Fig. 7

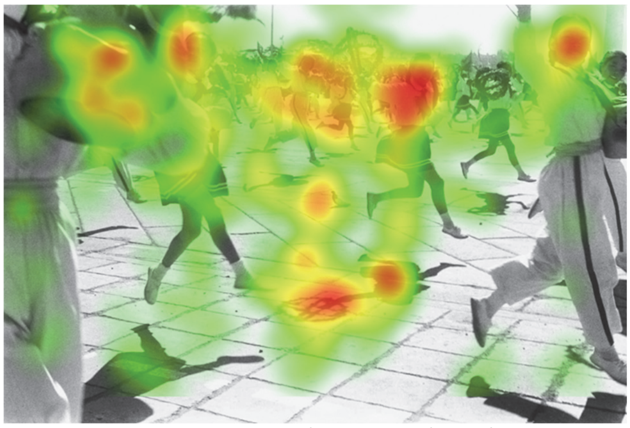

Figure 15 Heat map of the gaze data for Fig. 8

Fig. 16 and Fig. 17 show the averaged heat map and the gaze plot of one of the participants, respectively. From the heatmap, it can be seen that most fixations were on the subjects, while the shadows received less attention. However, when analysing the gaze plots, we observed the path that the eyes took and concluded that for this image, we could see that the diagonal shadows of the surrounding space had an influence on the gaze vector.

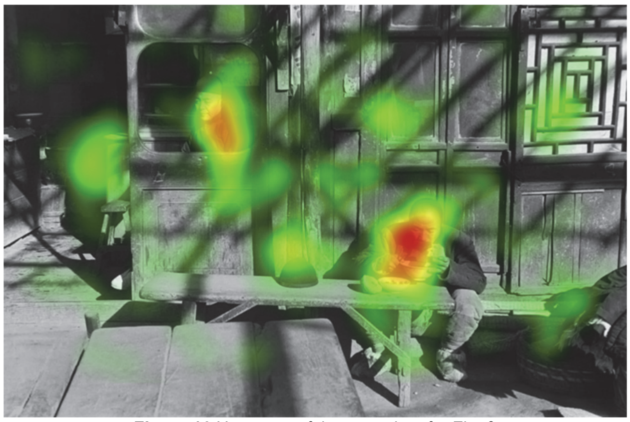

Figure 16 Heat map of the gaze data for Fig. 9

Figure 17 The sequence of gaze fixations for Fig. 9

In Fig. 18, the shadow of the surrounding space is actually perceived as an individual object. While each participant contributes a fixation on the person's face, the gazes are more dispersed in the area of the shadow. Nevertheless, the fixation count in the AOI of the tower shadow averages 7 (*SD* = 4), and in the AOI of the subject averages 3 (*SD* = 2). The average fixation duration in the subject's AOI was 0.26 ms (*SD* = 0.10 ms), while in the shadow it was 0.24 ms (*SD* = 0.08 ms), again indicating the equal importance of the elements, regardless of their physical presence.

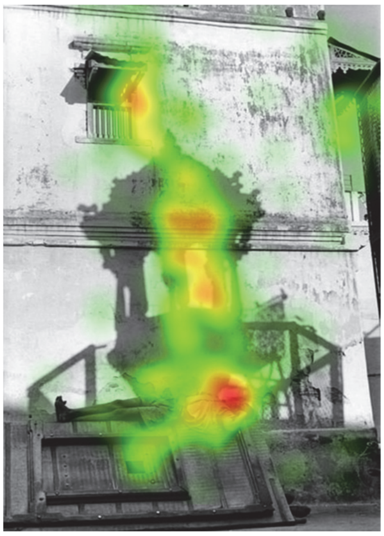

Figure 18 Heat map of the gaze data for Fig. 10

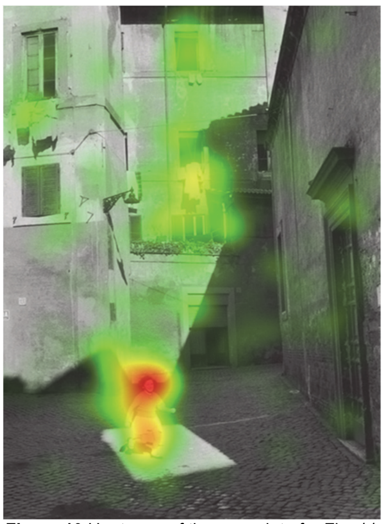

Figure 19 Heat map of the gaze data for Fig. 11

We have shown that participants tend to focus their gaze on the subject first, regardless of the image content. In Fig. 19, we show the heat map of gaze fixations for Fig. 11, in which we defined several AOIs, one of which contained only the subject and the second of which contained an additional bright rectangle around it. Analysing the times to first fixation, we found that the larger region containing the person and the illuminated area was perceived first, on average 0.46 ms faster (*SD* = 0.44 ms) than just the person. This shows how the light can draw additional attention to a particular area.

In Fig. 20, two main gaze areas can be seen, both referring to the subjects in the photograph. The average fixation count in the cat's AOI was 10 (*SD* = 4), whereas in the human shadow's AOI it was 3 (*SD* = 2). The cat was also observed first, as the time to first fixation was on average 2.45 ms shorter (*SD* = 2.13 ms) than for the person. The average fixation duration for the cat is 0.31 ms (*SD* = 0.12 ms) and for the human shadow 0.22 ms (*SD* = 0.11 ms). The fixations confirm that we perceive the shadow of a human as an actual human, while we associate the longer gaze fixations on the cat with the fact that there is more to see, e.g., more contrasts, textures, and elements of the cat's face.

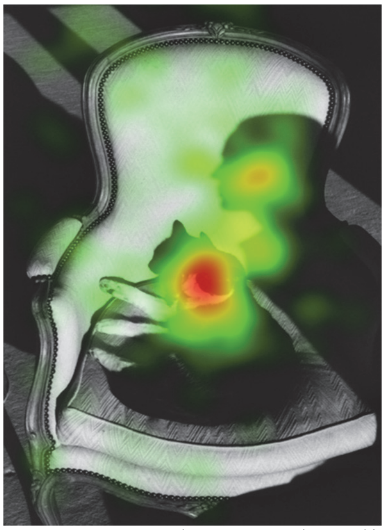

Figure 20 Heat map of the gaze data for Fig. 12

The last image in Fig. 21 illustrates our ability to read shadow shapes and associate them with their occluders. Two main gaze locations were located in the two AOIs we defined, the first being the shadow of a person in the center of the image, and the second being the silhouette of a person on the right. The average fixation duration for the shadow was 0.35 ms (*SD* = 0.18 ms), for the silhouette 0.36 ms (*SD* = 0.26), and in the other areas 0.22 ms (*SD* = 0.11 ms), indicating our tendency to detect and observe people. Interestingly, the total fixation duration in the shadow AOI was on average 1.28 ms longer (*SD* = 0.84 ms) than in the silhouette AOI. The average fixation count for the shadow was 4 (*SD* = 2), while for the silhouette it was 2 (*SD* = 1). This indicates that we can detect the slightly distorted shadow shape as well as the undistorted silhouette of a person, even if the person is not physically present.

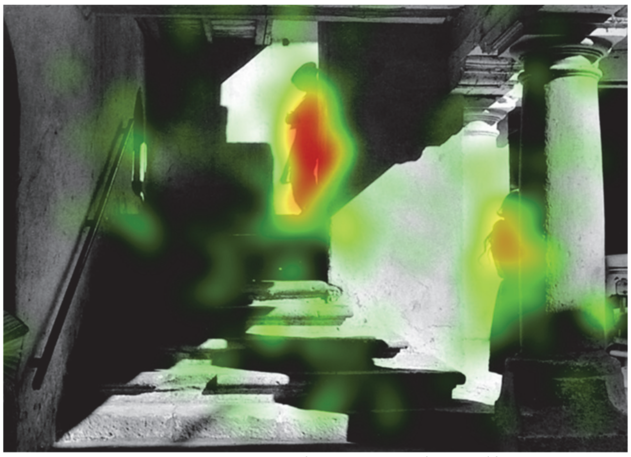

Figure 21 Heat map of the gaze data for Fig. 13

7.3 Correlation of the Methods and Results

To summarize the results of both methods, we gained insight into human perception of shadows, both descriptively and quantitatively. We used eyetracking to confirm the theoretical predictions we made earlier and to demonstrate that light and its absence, shadow, can play an important role in the perception of photographs and their content.

We have shown that unrecognized shaded objects can act as new objects, that we are able to associate an adjacent shadow with its occluder, that shadows can give an impression of the surrounding space, and even create a premonition of something that is about to happen.

Despite the large standard deviations in some quantitative results, they are still meaningful because we ensured that the relationships between the two correlated results were the same for all participants. In addition, we expected variations in the results because visual perception still contains subjective components. Therefore, the calculated standard deviations are natural to some extent, even though they do not refute the results.

8 CONCLUSION

Light is a complex, intangible substance so ordinary that one must be fully aware of it to actually perceive and understand it. This requires not only knowledge of physics, since it holds such a large role in subjective interpretation as well. As the introduction to this research shows, various fields of study give more thought to light than one would originally imagine. Art, psychology, rendering, video processing, and photography, all emphasize the importance of light and its influence on the perception of observed space. The use of light in photography can change the meaning of the image from positive to negative and vice versa. If the photographer is not aware of the enormous influence of light and the shadows produced, he lacks one of the crucial skills to control the result.

The question of how we perceive shadows is still not fully answered. Some insights have been gained through the results presented, but as researchers in the field of visual communication, we wonder how photographers perceive shadows since they, as professionals in their field, are aware of light and its consequences. Do they adjust lighting rationally, according to all their knowledge, empirically, that is, based on their experience, or purely intuitively? Are they aware of its textures, gradations, and versatility? This should be investigated further, as it would greatly enhance our understanding of the enormous impact of shadow on the realistic representation of space, as well as on the visual message an artist wishes to convey.

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