

# A computer graphics reconstruction and optical analysis of scale anomalies in Caravaggio's *Supper at Emmaus*

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## ABSTRACT

David Hockney has argued that the right hand of the disciple, thrust to the rear in Caravaggio's *Supper at Emmaus* (1606), is anomalously large as a result of the artist refocusing a putative secret lens-based optical projector and tracing the image it projected onto his canvas. We show through rigorous optical analysis that to achieve such an anomalously large hand image, Caravaggio would have needed to make extremely large, conspicuous and implausible alterations to his studio setup, moving both his purported lens and his canvas nearly two meters between “exposing” the disciple's left hand and then his right hand. Such major disruptions to his studio would have impeded—not aided—Caravaggio in his work. Our optical analysis quantifies these problems and our computer graphics reconstruction of Caravaggio's studio illustrates these problems. In this way we conclude that Caravaggio did not use optical projections in the way claimed by Hockney, but instead most likely set the sizes of these hands “by eye” for artistic reasons.

**Keywords:** Caravaggio, *Supper at Emmaus*, optical projection theory, Baroque art, optical aids, convex lens

## 1. INTRODUCTION

Caravaggio (1571–1610) was considered by many of his contemporaries to be the most important painter in Rome. He broke with the prevailing style of Mannerism by introducing a strong naturalism based on careful staging, dramatic and often raking lighting, and chiaroscuro. He was criticized for depicting religious subjects as *too* natural and for his employ of prostitutes and rough street people as models.

No documentary records from fellow painters, patrons, portrait subjects or critics who observed Caravaggio at work survive, and this has led to much speculation about his studio praxis. Christiansen, Puglisi and others have described Caravaggio's plausible working methods consistent with the stylistic and physical evidence, including the incision lines in the grounds found in several paintings.<sup>1,2</sup> A revisionist theory has been proposed as well—one that claims Caravaggio built a secret optical projector, illuminated his subjects by sunlight and projected their real images onto the canvas, traced these images and then filled in paint.<sup>3,4</sup>

One of the key works adduced in support of this theory, and the focus of our analyses, is *Supper at Emmaus*. David Hockney writes: [3, p. 120–121]

Caravaggio's new lens enabled him to attempt ever more complex and naturalistic images. Below is his *Supper at Emmaus* from between 1596–8 and 1601. Look at the remarkable foreshortened arms of St Peter on the right and Christ in the centre. ... Though we accept Caravaggio's representation as natural, if we look closer we see some strange discrepancies. Christ's right hand is the same size as Peter's, although it is supposed to be nearer to us; and *Peter's right hand seems larger than his left, which is also nearer*. These may be deliberate artistic decisions, or may be a consequence of movement of lens and canvas when refocusing because of depth-of-field problems. (emphasis added)

Here we test Hockney's projection claim for this painting through rigorous optical analysis and computer graphics reconstruction. In Sect. 2 we review the general hypothesis that Caravaggio employed optical projections directly while executing *Supper at Emmaus*. In Sect. 3 we analyze the optical explanation of the scale anomalies in the painting, and illustrate our results using computer graphics reconstructions and renderings. We conclude and summarize in Sect. 4.

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Figure 1. Computer graphics model of *Supper at Emmaus*. The figures have normal proportions, and the tableau is “optically accurate”—that is, it comports to the laws of physics and optics, including perspective and lighting. Of course, many realist artists, including Caravaggio, do not seek a “photographic” representation of the tableau before him. The use of such a computer graphics model exposes where he has or has not deviated from such an optically correct and consistent depiction of the tableau, for instance the size of the disciple’s right hand, thrust back into space—the focus of our study.

## 2. THE TRACING THEORY AND *SUPPER AT EMMAUS*

Caravaggio’s *Supper at Emmaus* depicts the Bible story in which the resurrected Christ reveals himself to disciples, 40 days after his crucifixion: “When He was at the table with them, He took bread, blessed and broke it, and gave it to them. Then their eyes were opened, and they recognized Him; and He vanished from their sight” (*Luke*, 24). While some painters such as Jacopo Pontormo (1525) depict the quiet of anticipation just *before* Christ is recognized, Caravaggio follows the more common approach of Titian (c. 1535) and others in depicting the ecstatic shock just *after* Christ is recognized. (We note in passing that the master forger Hans van Meegeren’s 1937 “masterpiece” was *Supper at Emmaus* in the style of Vermeer, which depicted the moment before revelation, comporting with Vermeer’s restrained style.<sup>5,6</sup>)

David Hockney has proposed that artists as early as Jan van Eyck (1385?–1441) and the Master of the Flémalle (Robert Campin, 1380?–1444) traced projected images in the early Renaissance, nearly a quarter millennium earlier than scholars have secure evidence any artist employed such a method. Hockney argues that this procedure was perhaps the most important reason for the rise in realism or “opticality” of the *ars nova* or “new art” of that time.<sup>3</sup> Over two dozen independent scientists, historians of optics, historians of art and prize-winning realist painters—including those in a four-day workshop devoted to testing Hockney’s theory—have examined the evidence for his claim, discovered new physical evidence, and have unanimously concluded by rebutting or rejecting Hockney’s tracing claim, at least for the early Renaissance. [7–11, and references therein]

The claim that the Baroque master Caravaggio used optics cannot be dismissed as easily. First, Caravaggio worked after the Renaissance, at a time of documentary evidence of appropriate projected images. Cardinal Francesco Maria del Monte, his first patron, was interested in science and Giambattista della Porta experimented with optical projections and wrote about them around this time. Thus Caravaggio had likely seen such projected images. There are technical difficulties in tracing a projected image that would have been quite dim,<sup>12</sup> but demonstrations or “re-enactments” show that it is *conceivable* the artist used optical projections.<sup>4</sup>



Figure 2. An overhead view or plan of our computer graphics model *Supper at Emmaus*.

Optical analysis has been used to argue in favor of the general projection claim,<sup>13</sup> and to rebut that claim. For instance, Robinson and Stork analyzed the optical claims by Hockney and Falco for their “Rosetta stone” work: Lorenzo Lotto’s *Husband and wife*.<sup>14</sup> In brief, Robinson and Stork used sophisticated ray tracing and lens design software to show that the setup in Hockney and Falco’s putative projector simply could not work as claimed. These rigorous optical simulations show that once the 116-cm-wide canvas is included in the Hockney and Falco optical setup, the projected image would not have gone in and out of focus in the way claimed by optical proponents, the process central to the optical explanation.

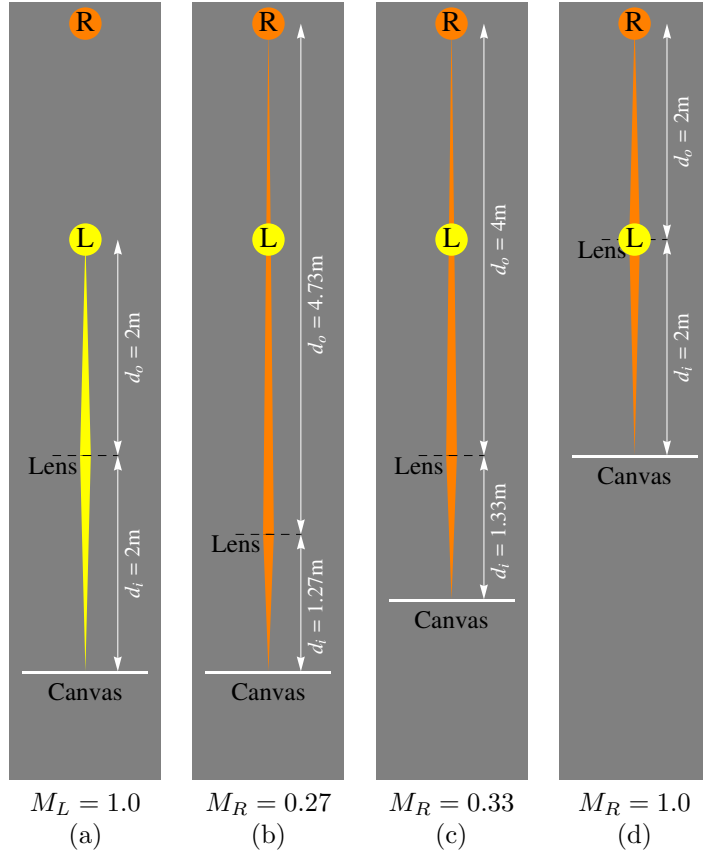


Figure 3. Overhead views or plans of schematic candidate optical setups for the “exposures” of the hands of the right disciple in *Supper at Emmaus* (cf. Fig. 2). The hands are represented by disks marked **L** and **R**, and the location of the converging lens and canvas are shown. Part (a) shows the setup for “exposing” the figure’s left hand. Because the empirical magnification of that hand is roughly 1.0, the object distance and the image distance must be twice the focal length. (The distances are illustrated in the case of  $f = 1\text{ m}$ .) In this setup the figure’s right hand would be out of focus and very blurry due to the limited depth of field of the projector. Part (b) shows the configuration if Caravaggio moved just his lens to focus the image of the right hand. The resulting magnification,  $M_R = 0.27$ , is far too small to be consistent with the empirical magnification of  $M_R \sim 0.9 - 1.0$ . Likewise, part (c) shows the setup if Caravaggio had moved just his canvas (screen) to focus the right hand. Again, the magnification,  $M_R = 0.33$ , is far too low to explain the empirical magnification of roughly 1.0. Part (d) shows the unique setup in which both the lens and canvas are moved to yield the empirical magnification of roughly 1.0. This setup is the same as in part (a), but moved forward by  $2\text{ m}$ , the distance separating the disciple’s hands. Such a large alteration within the studio, disrupting models, is implausible (cf. Fig. 4). If the focal length were shorter, then the shift position in part (d) would be even more extreme, with the lens being yet closer to the right hand than the left hand. If the focal length is larger, then total distance moved of both the lens and the canvas is proportionally larger as well.

### 3. OPTICAL AND COMPUTER GRAPHICS ANALYSES

Hockney and his colleague Charles Falco claim that some artists as early as 1430 secretly built optical projectors to project images onto canvas or other support and trace such images in some passages in some of their paintings.<sup>3</sup> Their arguments for works in this era are based primarily on concave mirrors. The argument for *Supper at Emmaus* relies instead on a convex lens, much like a simple camera obscura, as described in the quotation above.

The laws of optics and imaging allow us to test Hockney’s projection claim for this work. The distances between an object, lens and the focussed image on the canvas (screen) are governed by the lens equation,

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}, \quad (1)$$

where  $f$  is the focal length of the lens,  $d_o$  the distance of the object from the lens and  $d_i$  the distance of the focussed image to the lens. [15, p. 418] The magnification or ratio of size of the image to the size of the object is equal to the ratio of the image to object distances, that is,  $M = d_i/d_o$ , and is related to other parameters by: [15, p. 420]

$$f = d_o \frac{M}{1 + M}. \quad (2)$$

Here we denote the magnification of the left hand as  $M_L$  and the right hand  $M_R$ ; this magnification will depend upon the setup under consideration.

Such a lens has a limited depth of field, or range of objects that are acceptably in focus.<sup>15</sup> An optical system’s depth of field depends upon the focal length and diameter of the imaging element (here, convex lens) and the criterion of “acceptably in focus,” which is usually specified by the size of the blur spot, or range of positions on the screen illuminated by light from a single point on the object. The depth of field for lenses with plausible parameters at the time of Caravaggio would not encompass the two hands of the disciple. Thus, if Caravaggio used a projector, he would have had to refocus between “exposures” of the hands—just as Hockney surmises.

In *Supper at Emmaus*, the size of the image of the left hand is 17 *cm* and the right hand is 16 *cm*. Of course, we cannot know the size of the actual hand of the model, but our analysis does not require us to know it precisely. We invoke only the assumption that the model’s hands are of equal size which we take to be 17 *cm* across. For this painting the empirical magnifications are then roughly 1.0. The slight difference in magnification between the left and right hands affects our results by just a few percent and will not change our overall conclusion.

Given that the empirical magnification of the left hand is approximately  $M_L = 1.0$ , Eq. 1 demands that the object distance and image distance be  $d_o = d_i = 2f$ , as illustrated in Fig. 3 (a). The limited depth of field of the projector implies the disciple’s right hand would be out of focus. Following Hockney, we imagine how Caravaggio might have proceeded. The most natural step would be for him to focus on the right hand by moving the lens. After all, the lens is small, and likely easily moved, as is common with burning lenses. Figure 3 (b) shows the setup where just the lens is moved for refocusing. The distances marked are given by Eq. 1, and the resulting magnification is  $M_R = 0.27$ . This magnification differs by nearly a factor of four from the empirical magnification of the painting and we thus conclude that Caravaggio did not move merely his lens alone.

What if Caravaggio had kept his purported lens fixed but moved just the *canvas* to refocus on the right hand? Figure 3 (c) shows this case, where, as before, all the distances are governed by Eq. 1. The resulting magnification for the right hand is now  $M_R = 0.33$ —again, far too small to be consistent with the evidence in the painting.

What if Caravaggio had moved *both* the lens and the canvas, as Hockney hypothesizes? To obtain the empirical magnification of roughly 1.0, Caravaggio would have to duplicate the setup of part (a), but shifted forward by 2 *m*, as shown in part (d). Such a rearrangement to his studio would have been severe indeed. Moreover, the size of the image of the head would have been roughly three times as large as in the setup of part (a). This disruption to the studio would be compounded by the rearrangement of the baffles needed to block the sunlight from the canvas. Moreover, realist artists generally move between passages, altering and adjusting poses, sizes, texture, and so on, and the presence of the projector and the difficulty in refocusing would impede, rather than aid, the artist. Surely these extremely large rescaling would have at least caught the artist’s, subjects’ and others’ attention.

What would the image on the canvas look like in these different setups?

Figure 4 (a) shows the view from the position of lens placed 2 *m* in front of the left hand, corresponding to Fig. 3 (a) and (c). The disciple’s right hand is one-half the size of the left, because it is twice as far from the lens. These computer graphics renderings reveal the spatial arrangement of the image on the canvas, though the image in the actual screen would be very dim, inverted, and would vary in sharpness due to the projector’s limited

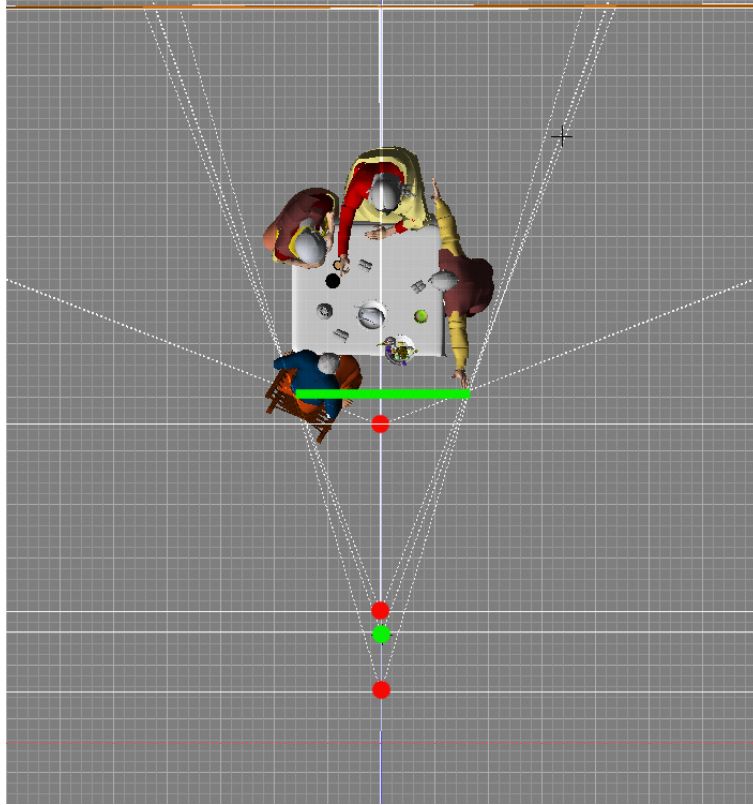


Figure 4. Computer graphics renderings of the views from the lens positions in Fig. 3. The images projected onto the canvas in these setups would be inverted and much dimmer than are shown here and would reveal depth of field problems. Part (a) shows the view from  $2\text{ m}$  in front of the left hand, from  $2.73\text{ m}$  in front of the left hand and directly at the position of the left hand.

depth of field. Figure 4 (b) shows the view from  $1.73\text{ m}$  in front of the left hand, corresponding to Fig. 3 (b). Figure 4 (c) shows the view from very close to the left hand, corresponding to Fig. 3 (b).

If the focal length of the putative lens were larger than  $f = 1\text{ m}$ , then there would be an even greater disruption to the setup—greater movement between refocusing. Moreover, other figures at different distances would appear at greatly anomalous sizes—more anomalous than we find.

## 4. CONCLUSIONS

We demonstrated that a key scale anomalies in Caravaggio's *Supper at Emmaus* identified by David Hockney—that of the hands of the apostle at the right—are quite unlikely to have arisen from the refocusing of a convex lens projector. Neither the “natural” refocussings—changing the lens alone, or of changing the canvas alone—are compatible with the laws of basic optics and the scale of the depiction of the right hand in the painting. The most plausible optical setup demands that *both* the canvas and the lens be moved, each by roughly two meters. To be consistent with the scale of the right hand, the “exposure” of that hand requires the lens to be near the location of the figure's left hand.

One might try to salvage the projection claim for this painting by introducing new, ad-hoc optical systems—multiple lenses, mixtures of lenses and plane mirrors, mixtures of lenses and concave mirrors, substitution of lenses of different focal lengths when executing different passages, etc.—but such a new theory would be not only more implausible on technological grounds, it would suffer from the methodological flaw of altering an explanation to “confirm” a pre-conceived “conclusion.” Such an approach would be methodologically vacuous.

Recall that Hockney wrote of the scale discrepancies in this painting: “These may be deliberate artistic decisions, or may be a consequence of movement of lens and canvas when refocusing because of depth-of-field problems.” Our conclusion supports his former hypothesis: the scale anomalies were deliberate artistic decisions.<sup>16</sup>

## ACKNOWLEDGMENTS

The first author expresses thanks to Caravaggio scholars David M. Stone (University of Delaware), Lorenzo Pericolo (National Gallery Washington), Keith Christiansen (Metropolitan Museum of Art), and John Spike (Florence), and to scholars of early optics Sara Schechner (Harvard University) and Michael John Gorman (Arkimedia) for helpful discussions.

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