Did early Renaissance painters trace optical projections? Evidence pro and con

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Abstract

Recently it has been theorized that some European painters as early as 1420 used concave mirrors (and, later, converging lenses) to project real inverted images onto their supports which they then traced and painted over. We review the image analytic, historical and art historical evidence and counter-evidence for this bold claim, focusing on key paintings in the debate. While some of the evidence is consistent with the use of optical projections in the 15th century, all such evidence is also consistent with other explanations as well. More importantly, for those paintings highlighted as supporting the projection theory, there is much evidence that is *in*consistent with the use of optics or extremely difficult to explain as arising from the use of optics. Further, there is no historical documentary evidence from the 15th century suggesting anyone had even seen an image of an illuminated object projected onto a screen—the first step in the proposed projection method. The projection method would have been the most sophisticated optical procedure of its day, which theory proponents speculate was discovered by artists, not the scientists who were actively exploring optical systems. Because the burden of proof lies foursquare upon the theory's proponents—the revisionists—in the absence of compelling reasons to reject "traditional" (non-optical) explanations we must reject the projection theory. We conclude by rejecting the claims that the optical projection theory has been "proven."

Introduction

The artist David Hockney recently claimed that as early as 1420 some Renaissance masters used optical instruments and their projections as aids when painting [1–3]. Specifically he and his collaborator, thin-film physicist Charles Falco, claim that some artists, starting in the early 15th century, traced inverted real images that they projected onto their canvases or other supports. For works in oil the artist would then, according to the theory, turn the support right-side up and apply paint. It is well known that some 18th- and 19th-century painters—such as the Venetian Canaletto (1697-1768) and English artists Joshua Reynolds (1723-92) and William Hyde Wallaston (1766-1828)—traced such projections of bright, outdoor scenes; there remain, too, scholarly debates over whether the late-17th-century Dutch master Jan Vermeer (1632-75) traced projections for his indoor images [4]. The earliest record of an image of an illuminated object projected onto a screen by an optical element (converging lens or concave mirror) is around 1550 and the earliest record suggesting that such an image might be *traced* appears in 1558, from the magician and optical experimenter Giambattista della Porta [5]. The earliest documents that show anyone *in fact* traced a projected image date from 1603, describing the scientist Johannes Kepler tracing an image of an outdoor scene. In short, in the early 15th century and for over a century thereafter we have no corroborating documents from artists, patrons, scientists, mirror makers, art critics or others stating that anyone had even *seen* a real image of an illuminated object projected onto a screen by any optical instrument (converging lens or concave mirror), much less trace or paint over it—this despite the fact that numerous other optical devices, drawing aids, treatises on perspective, and so forth, from that time are well documented [6]. Hockney's specified date is nearly a quarter of a millennium earlier than when we have secure corroborating evidence anyone traced over the image of an illuminated object projected onto a screen. In the absence of persuasive documentary evidence, most of the analyses and

debate over the projection theory have concentrated on the paintings themselves as primary evidence.

We provide an overview of the case for and against the artistic use of optical projections in European painting as early as 1420, touching upon the range of topics and types of evidence. Our goal is to serve as an introduction to the debate and references, not to present full explanations and arguments; details are in the cited references. In Sect. *I* we sketch relevant properties of Hockney's theory, then in Sect. *II* examine general arguments for and rebuttals against the use of optical projections in the early Renaissance. Then in Sect. *III* we summarize the arguments over specific paintings adduced as evidence by Hockney and Falco. We conclude in Sect. *IV* with a few general remarks.

I. Optical projection theory

As mentioned above, Hockney's optical projection theory states that some European painters as early as 1420 employed optical devices, specifically concave mirrors, to project real inverted images of a brightly lit scene or part of a scene onto a canvas or other support (paper, oak panel, etc.). According to the theory, artists would then either trace in pencil the image contours and then commit paint to the support, or perhaps even paint directly [1], though Hockney admits that it is extremely difficult to paint directly under optical projections. Hockney's projector is, in essence, a mirror-based *camera obscura*, and as such would produce images that obey the laws of perspective, images that would be much dimmer than the original scene [7].

Part of Hockney's motivation in proposing his optical theory was the celebrated rapid rise in realism of the *ars nova* or "new art" in Europe at the beginning of the Renaissance, a property he dubbed "opticality" or "the optical look." He doubted whether such a rise could have come by artists merely drawing and painting more accurately and suggested instead they were influenced by the mere sight of images (presumably ones projected onto a screen, of which we have no independent evidence), and that they ultimately exploited such images directly in their praxis.

II. General arguments and rebuttals

In this section we consider a number of general issues in the debate; any given issue might apply to a few individual paintings that we consider in Sect. *III*, as should be clear.

Documentary evidence

Hockney and Falco and historians of science and art have provided no documentary evidence for the projection procedure in the early Renaissance. Hockney and Falco have pointed to passages from the 13th-century ***Roman de la Rose*** as evidence for mirror projections [8]; indeed these passages confirm the well-known fact that people saw optical projections (into space). However, these passages do *not* document even the first step in the projection procedure, i.e., that anyone had seen an image projected *onto a screen* (wall, canvas, …). Seeing a projection onto a screen is far more difficult than what appears in the ***Roman***, for at least three reasons: No optical system of its day required the high quality in optical form, stringent illumination (direct sunlight on the subject, dark shade on the support) and careful alignment and inter-element separations. While Hockney's optical projector design is elementary by 21st-century standards, in the 15th century such a projector would have been the most sophisticated optical system on the planet.

Hockney and Falco have suggested that artists using the projection technique would not have revealed the method, because they feared the wrath of the Inquisition. This explanation is implausible, as the Catholic Church supported and relied on nearly all the artists in question; the Church instead suppressed dissent to its *doctrine.* While alchemists were indeed frightened of the Inquisition, other trades at that time were not, generally speaking [9].

Falco speculates that artists did not write down their purported optical discoveries lest such writings reveal trade secrets to competitors. In fact, however, as Pamela O. Long's study describes so well, tradesmen in the early Renaissance advertised and made known their techniques as a way to get both apprentices and patrons and as a matter of professional pride [9]. Even if the few cases where specifics of their methods were secret, knowledge that such secrets *existed* were often widely known, as for instance the trade secrets of the celebrated Venetian glass makers. For instance, Mariano Taccola (1382-1458?) wrote treatises that clearly and openly display his complicated mechanical and hydrodynamic inventions. While there are occasionally passages when he states he is withholding information, he intimates that he will reveal these to any patron who employs him [9, p. 115]. In short advertising that one *had* a trade secret was a way to promote ones work. We have no such documentary evidence *about* an optical projection "trade secret" from practitioners in the 15th century.

Early Renaissance visual artists had great motivation to reveal a technical basis of their work; after all, this was an era when the arts were striving to rise in stature among the liberal arts. Placing the arts

on a technical foundation would have served this end as indeed did the numerous treatises on perspective from this time.

Hockney and Falco speculate that artists did not have time to write about their purported optical discoveries (presumably a few hours, at most), since they were busy painting. It seems far more likely that artists did not have the months or years or even decades to figure out the most sophisticated optical system and procedure on the planet—a procedure that eluded the finest optical scientists of the day, including Alhacen (965?-1040?), Erazmus Ciokek Witelo (1220-80) and Roger Bacon (1214?-94?), all who eagerly explored optics and wrote copiously about their experiments. Given that many other drawing aids and optical techniques are described in the early Renaissance, it is hard indeed to understand why the specific method required by the projection theory would elude the documentary record.

The projection proponents' speculations about the lack of documentary evidence do not comport with the evidence.

Availability of adequate optical devices

It is well known that concave mirrors existed at the time of van Eyck and indeed earlier but these were of short focal length as was appropriate for their use in burning and reading [10]; these had a focal length much shorter than that implied by the projection theory [2]. Even if we overlook this matter of the incommensurate focal lengths, we can ask: Were there devices otherwise adequate for Hockney's projection method? Sara Schechtner has pointed out that 15th-century optical devices surviving in museum collections—specifically glass and metal concave mirrors—and contemporary references to them, show that they were of too poor a quality to provide an aid to artists [11]. While modern technologists could of course create an adequate device *ex post facto*, even using methods that might have existed in the 15th century, such an exercise would shed little, if any, light on the era in question. For instance it would be a simple matter to create a primitive battery using material available many centuries before Alessandro Volta invented his "pile," or a telescope using devices available centuries before its known invention date. Such exercises ignore the significant role of contemporary knowledge in the creation of these landmark technical achievements. For projections onto a screen, there was little or no contemporary understanding of ray tracing or many other later technical notions that underpinned the method.

In short, we have little reason to believe that optical devices of sufficient quality for Hockney's procedure were available at the beginning of the Renaissance.

Modern "re-enactments"

Most of Hockney's demonstrations of his procedure have relied on large, modern high-quality concave mirrors and high-power, easily directed electrical theatrical stage lighting with Fresnel lenses, neither of which finds support in the historical record. Demonstrations using direct sunlight are of little relevance to the many paintings that depict interior scenes, such as the *Arnolfini portrait* or *Mérode Altarpiece*, and for which we have no independent evidence the artist worked outdoors. To this author's knowledge, to date Hockney has not displayed publicly a full *painting* created by his projection technique. Even if such "re-enactments" were done properly (i.e., using only devices of quality known to exist in the early Renaissance, appropriate illumination, etc.), these re-enactments might at best be *consistent* with the use of optics in the 15th century, neither proof that the method was used nor especially that it provided any benefit over painting "by eye."

Tracing as an aid to realism or "opticality"

Hockney claims that tracing an optical projection can lead to a greater realism or "opticality." This speculation has had little if any support. Simple, informal experiments suggest that it is *color* and *shading*—not *form* and *contour*—that better correlates with the celebrated realism in the *ars nova* [7]. Hockney's projection method does not significantly aid artists in the rendering color and shading any more than the outlines in a child's coloring book aid in the rendering of color and shading. Instead, the introduction of oil paint, with its many special properties seems more relevant. Oil paints afford a wider ranger of lightness (whiter whites, blacker blacks), wider range of saturation (richer, more intense colors), novel glazing and layering techniques, and greater control in mixing colors on the support than did earlier media such as gesso and tempera. Most importantly, oil paints dry *slowly*, allowing the painter to work and rework and image over months or years.

As yet it is undemonstrated that the projection technique enhances the realism or "opticality" of paintings. More to the point, it remains undemonstrated that the projection method provides a shortcut or benefit over "eyeballing" (painting without the use of optical projections) as far as achieving "the optical look."

"Left-handed" subjects

Hockney points to what he believes is a surfeit of "left handed subjects" in paintings beginning around 1600 as evidence of artists switched from using a concave mirror to using converging lens [1]. It is a simple consequence of geometrical optics that while a

projection by concave mirror leaves the spatial symmetry of the image the same as the source tableau, a projection by converging lens will reverse the symmetry, that is, a right-handed subject will appear left-handed in the final painting [2].

Even if there were a surfeit of left-handed figures in paintings of that time (a claim that has not yet received adequate support), there are a number of traditional (i.e., non-optical) explanations for left-handed figures in paintings. For instance, Western viewers prefer the illumination to flow from upper left to lower right across the image, and a left-handed subject—holding, say, a goblet—would not cast a shadow on his body.

But the optical explanation for left-handed subjects suffers from a severe obstacle. According to Hockney, the painter would trace a projected image, then turn the painting right-side up and apply paint while viewing the scene directly. This means that the artist would be viewing a *right-handed* subject while applying paint to a (reversed) *left-handed* image on the support. To this author's knowledge, no one has "re-enacted" the creation of a full painting by this proposed method. Applying paint to the image reversed from what one sees presents a significant cognitive challenge, an impediment compared to painting "by eye."

Painting genres that elude the projection method

There are a number of types of paintings that elude Hockney's projection method. Of course moving objects—running horses, restless putti, etc.—cannot be captured because their projected images move before the artist can trace them. Self-portraits cannot be painted using projections as the subject/painter would have to be simultaneously inside and outside the *camera obscura*. Murals cannot be painted directly using a concave mirror projection because the image would be upside-down [12]. (Later techniques from the second half of the 16th century, employing additional mirrors or lenses overcome this drawback, however.) While analyses of these genres of course do not *disprove* the projection theory for other specific works, they show that artists of the time could render highly realistic "optical" paintings without recourse to the use of optical projections. Thus for those specific paintings where there is insufficient evidence to conclude optics were used, the philosophical principle of Occam's razor dictates that we must reject the projection claims.

III. Specific paintings

We now consider some of the particular paintings adduced by Hockney and Falco as supporting their theory. Many of the general concerns from Sect. *II* apply to these specific works, as should be clear.

Jan van Eyck's *Portrait of Arnolfini and his wife* (1432)

Jan van Eyck's *Portrait of Arnolfini and his wife* is a key painting in the projection theory, and the theory's proponents have made a number of claims about it. They surmise that the famous blown glass con*vex* mirror depicted within the work could have been turned around and used by van Eyck as a con*cave* projection mirror [1]. However, there are a number of technical problems with silvering the outside of a blown glass and we have no such mirrors surviving in museum collections or documentary records for the creation of mirrors this way. Such a large mirror would have a blur spot larger than 1 cm in diameter and hence much too large for capturing fine detail we find in the painting; any of the inevitable deviations from a proper optical shape would degrade the image yet further [12]. More crucially, however, rigorous computer image analysis shows that the focal length of the depicted mirror is far too short to be consistent with the focal length of a putative projection mirror for the full image [13,14].

The full image in the painting reveals a number of perspective inconsistencies that are hard indeed to explain as arising from optical projections. Even small image patches (which would have been created under a single putative projection "exposure") have inconsistent perspective, thereby arguing against the use of projections. Moreover, infrared reflectography reveals significant underdrawing throughout the painting, hardly evidence of the use of a traced image [15]. The only passages without underdrawings are the small dog, which surely was added to the painting late (and unlikely to have been done under projections of a restless dog model), and the splendid chandelier, which we consider next.

Hockney claims the Arnolfini chandelier "is in perfect perspective" and hence likely created by tracing a projected image [1,16]. A simple perspective analysis shows that the painting is incompatible with the claim that a projection of a *spatially symmetric* chandelier was traced [13,14]. The question then arises, how asymmetric a chandelier is consistent with the optical projection explanation, and is such asymmetry representative of decorative metalwork of the 15th century?

The best way to address the first part of this question is to estimate the perspective transformation needed to align one chandelier arm with another, perform this transformation, and compare the shapes of the perspective-aligned arms. Though it is unclear from the proponents' writings, it seems plausible they adjusted perspective transformations "by hand" using commercial software such as Adobe Illustrator to this

end [3]. By ignoring the crockets and other decorative structures, for instance, such an approach could yield a perspective transform that aligns well the candleholders or *bobeches*, just as the theory's proponents report. In contrast, the theoretically proper estimation method is to use an over-constraining set of points on two arms. This method avoids the possibility an experimenter would confirm a desired symmetry result by choosing both the small subset of corresponding points as well as the points to report for the final misalignments [16,17].

Regardless of the estimation procedure, the inter-arm variation is as much as 10 cm in Arnolfini's room. While Hockney and Falco try to dismiss this large inter-arm variation as arising from sloppy hand craftsmanship (riveting or soldering decorative structures to a main arm), their explanation is contradicted by a number of sources. Experts in 15th-century metalwork confirm that arms were cast from the same mold or "model," thereby ensuring great similarity of form. Next, direct measurement *in situ* and photogrammetric analysis of photographs of 15th-century metalwork surviving in museum collections, reveal typical inter-arm variations are roughly a mere millimeter. In short, to be consistent with the projection claims, the physical Arnolfini chandelier would have had to have been extraordinarily deformed—roughly two orders of magnitude more deformed than comparison metalwork surviving in museum collections [17].

Moreover, modern realist artists can paint large, complex chandeliers in excellent perspective, surpassing that of the Arnolfini painting, entirely "by eye," that is, without projections, photographs or geometrical image constructions [16,17]. Might this be due to the fact that these artists have seen photographs or other images in accurate perspective? This seems quite unlikely. The vast majority of people today—and even most trained artists—have seen innumerable photographs, movies and other images in correct perspective yet cannot paint such a chandelier in good perspective "by eye." The artists who *can* paint in accurate perspective by eye are those who do what we know early Renaissance artists did: they spent years or decades of careful drawing from life.

Jan van Eyck's *Portrait of Niccolò Albergati* (1431 and 1432)

In 1431, Jan van Eyck executed a small study in silverpoint of Cardinal Niccolò Albergati and in 1432 a copy roughly 40% larger in oil on panel. Hockney and Falco claim the oil version was copied and enlarged from the silverpoint using an epidiascope or primitive opaque projector [1]. They base this claim on two features: the high fidelity of the (scaled) copy and at least two distinctive "relative shifts" of portions of the image. They explain these shifts as arising from van Eyck accidentally bumping his optical setup in mid-completion.

Their explanation has a number of awkward implications. The most salient is that van Eyck, working closely on an important commission, would surely have seen the mismatch between the tracing already committed and the now-shifted image from the bumped epidiascope and would have corrected such an "error" had he so wished. In short, it is very implausible that the oil version was the result of a "mistake." More importantly, the recent discovery of tiny pinprick holes in the silverpoint source show that mechanical (not optical) copying and enlarging was used, for instance by a *Reductionszirkel* or *compasso da reduzione*, a simple device known from Roman times. Modern re-enactments using only such mechanical technology reproduce the fidelity and can reproduce the "errors"—relative shifts—as the artist chooses a new fiducial point [18–21]. Moreover, when copying/enlarging with a *Reductionszirkel*, van Eyck would not have seen any offset between an outline committed to the support and a shifted image.

Robert Campin's *Mérode Altarpiece* (1426)

Hockney and Falco claim that the "perspective anomalies" in the trellis in the right panel of Robert Campin's *Mérode Altarpiece* are due to the refocusing of a projector [3]. Falco claims to have discovered a "break" in the edge of the workbench due to the same purported refocusing a concave mirror. In fact, though, this "break" is due instead to St. Joseph's elbow and has nothing whatsoever to do with refocusing.

More importantly, a simple and far more plausible geometrical construction using straightedge or ruler reproduces the "perspective break" in the trellis and does not require the most complicated optical system of its day nor severe lighting constraints within the manifestly indoor tableau [13].

Hans Memling's *Flower still-life* (c. 1490)

Hockney points to the carpet in Hans Memling's *Flower still-life* as evidence of projections. Specifically he and Falco note that the (somewhat indistinctly defined) central vanishing point of the front half of the carpet differs from that of the back half, as might arise if Memling refocused a projector to overcome its limited depth of field [1]. However additional perspective tests show the image is strongly *inconsistent* with such a projection [22]. Specifically, lines at an angle that should meet at a vanishing point on the same horizon line as the central vanishing point, in fact do not. This angular deviation from perspective consistency is more than twice as great as the angular deviation adduced as evidence for refocusing. In short, the evidence

against the claim each half carpet was in perspective is twice as well established as the evidence that the central vanishing point was changed for whatever reason.

Caravaggio's *Supper at Emmaus* (1600-1)

Hockney points to an anomalously large hand as evidence for refocusing and repositioning a concave mirror or lens [1]. However, a simple application of the mirror equation shows that such refocusing would have demanded a very large, awkward and implausible alteration to the studio setup [23]. This counter-argument applies to projections by a concave mirror or a converging lens, which obey the same "lens equation." The disruption to the studio is severe.

Caravaggio's *Bacchus* (c. 1597)

Hockney points to the fact that the figure in *Bacchus* holds a glass in his left hand as evidence Caravaggio used a lens (rather than a concave mirror) [1,16]. As discussed in Sect. *III*, painting a left-handed figure on the support while viewing a right-handed figure is extraordinarily difficult. Moreover, this artist's *Sick Bacchus* (c. 1593-4) is generally considered to be a self-portrait, and hence could not have been created by projections. Given that *Sick Bacchus* was not created by optical projections, it seems at least plausible that neither was the stylistically similar figure in *Bacchus*.

Lorenzo Lotto's *Husband and wife* (c. 1543)

Hockney and Falco claim that anomalies in the carpet in Lorenzo Lotto's *Husband and wife* are due to refocusing and repositioning a concave mirror projecting the [2]. However, their explanation relies fundamentally and crucially upon their assumption that the keyhole pattern is spatially symmetric. In fact, though, 16th-century "Lotto carpets" surviving in museum collections are asymmetric [24], implying the Hockney/Falco optical fits are meaningless. Moreover, the projection theory predicts that perspective should be locally coherent (i.e., within a putative "exposure") and globally incoherent (i.e., between separate putative "exposures") but the evidence shows just the opposite [25,26].

Hockney and Falco point to the coarser section in the keyhole in the image as evidence a projection was "out of focus" [2]. There are severe problems with this explanation the most salient being that it is based on a contradiction, i.e., that Lotto *refocused* his mirror (to explain a "perspective break") yet the region is nevertheless "out of focus." Moreover, it seems highly implausible that Lotto would have traced the tiny details in this region. Finally, there are a number of non-optical explanations of the coarse region, such as a change in mixture between pigment and lake, or the use of brushes of the same width as used elsewhere on the rug, or subsequent repainting or crushed pile from kneeling prayers.

Georges de la Tour's *Christ in the carpenter's studio* (1645)

Hockney claims Georges de la Tour's *Christ in the carpenter's studio* was created by projection using bright light from outside the tableau [1] but careful analysis of shadows shows instead the illumination was likely the candle within the tableau, a result that is incompatible with the optical explanation [27]. Similar analyses of de la Tour's "nocturne" paintings show that these too are in all likelihood painted under the illumination depicted within the paintings, particularly the following works: *Magdalen with the smoking flame* (c. 1640), *Magdalen of the night light* (1630-35), *The New-born* (1640s) and *Woman catching fleas* (1630s). All these works show the sharp shadows consistent with the location of the single candle depicted within the painting, a result arguing against projections.

IV. Conclusions

We reiterate that fact that the burden of proof lies foursquare upon revisionists, in this case the proponents of the projection theory [28,29]. While there is indeed some evidence consistent with the optical projection theory, all this evidence is consistent with non-optical explanations as well, as we have seen. Moreover, we have seen specific, rigorous tests showing evidence inconsistent with the use of optics in painting as early as 1420.

In light of the growing results from a range of scholars using a range of methods seems prudent to reject the frequent, highly public claims that the optical projection theory has been "proven" [30].

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