Studies on Binocular Vision

Archimedes

NEW STUDIES IN THE HISTORY AND PHILOSOPHY OF SCIENCE AND TECHNOLOGY

VOLUME 47

EDITOR

JED Z. BUCHWALD, *Dreyfuss Professor of History, California Institute
of Technology, Pasadena, CA, USA.*

ASSOCIATE EDITORS FOR MATHEMATICS AND PHYSICAL SCIENCES

JEREMY GRAY, *The Faculty of Mathematics and Computing,
The Open University, Buckinghamshire, UK.*
TILMAN SAUER, *California Institute of Technology*

ASSOCIATE EDITORS FOR BIOLOGICAL SCIENCES

SHARON KINGSLAND, *Department of History of Science and Technology,
Johns Hopkins University, Baltimore, MD, USA.*
MANFRED LAUBICHLER, *Arizona State University*

ADVISORY BOARD FOR MATHEMATICS, PHYSICAL SCIENCES AND TECHNOLOGY

HENK BOS, *University of Utrecht*
MORDECHANI FEINGOLD, *California Institute of Technology*
ALLAN D. FRANKLIN, *University of Colorado at Boulder*
KOSTAS GAVROGLU, *National Technical University of Athens*
PAUL HOYNINGEN-HUENE, *Leibniz University in Hannover*
TREVOR LEVERE, *University of Toronto*
JESPER LÜTZEN, *Copenhagen University*
WILLIAM NEWMAN, *Indian University, Bloomington*
LAWRENCE PRINCIPLE, *The Johns Hopkins University*
JÜRGEN RENN, *Max-Planck-Institut für Wissenschaftsgeschichte*
ALEX ROLAND, *Duke University*
ALAN SHAPIRO, *University of Minnesota*
NOEL SWERDLOW, *California Institute of Technology*

ADVISORY BOARD FOR BIOLOGY

MICHAEL DIETRICH, *Dartmouth College, USA*
MICHEL MORANGE, *Centre Cavaillès, Ecole Normale Supérieure, Paris*
HANS-JÖRG RHEINBERGER, *Max Planck Institute for the History of Science, Berlin*
NANCY SIRAI, *Hunter College of the City University of New York, USA*

Archimedes has three fundamental goals; to further the integration of the histories of science and technology with one another: to investigate the technical, social and practical histories of specific developments in science and technology; and finally, where possible and desirable, to bring the histories of science and technology into closer contact with the philosophy of science. To these ends, each volume will have its own theme and title and will be planned by one or more members of the Advisory Board in consultation with the editor. Although the volumes have specific themes, the series itself will not be limited to one or even to a few particular areas. Its subjects include any of the sciences, ranging from biology through physics, all aspects of technology, broadly construed, as well as historically-engaged philosophy of science or technology. Taken as a whole, *Archimedes* will be of interest to historians, philosophers, and scientists, as well as to those in business and industry who seek to understand how science and industry have come to be so strongly linked.

More information about this series at <http://www.springer.com/series/5644>

Dominique Raynaud

Studies on Binocular Vision

Optics, Vision and Perspective
from the Thirteenth to the Seventeenth
Centuries

Dominique Raynaud
PPL
Université Grenoble Alpes
Grenoble
France

ISSN 1385-0180

Archimedes

ISBN 978-3-319-42720-1

DOI 10.1007/978-3-319-42721-8

ISSN 2215-0064 (electronic)

ISBN 978-3-319-42721-8 (eBook)

Library of Congress Control Number: 2016946944

© Springer International Publishing Switzerland 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer International Publishing AG Switzerland

Preface

The aim of this book is to elucidate the question of the interrelationship between optics, vision and perspective before the Classical Age. In the Middle Ages and the Renaissance, the concept of *Perspectiva*—the Latin word for optics—encompassed many areas of enquiry that had been viewed since antiquity as interconnected, but which afterwards were separated: optics was incorporated into the field of physics (i.e., physical and geometrical optics), vision came to be regarded as the sum of various psycho-physiological mechanisms involved in the way the eye operates (i.e., physiological optics and psychology of vision) and the word ‘perspective’ was reserved for the mathematical representation of the external world (i.e., linear perspective).

However, this division, which emerged as a result of the spread of the sciences in classical Europe, turns out to be an anachronism if we confront certain facts from the immediately preceding periods. It is thus essential to take into account the way medieval scholars posed the problem—which included all facets of the Latin word *perspectiva*—when exploring the events of this period. What we now recognize as a ‘nexus’ between optics and perspective was at the time in fact seen as a single science. I submit that the earliest developments in linear perspective cannot be elucidated without reinserting them into the web of ideas that originally constituted *perspectiva*.

The central focus of this book is the theory of binocular vision, which has been virtually ignored in the field of perspective studies. This theory generated one of the most puzzling alternatives to linear perspective in the history of representation—two-point perspective which could be regarded as a ‘heterodox system’ inasmuch as linear perspective is taken to be the norm. However, linear perspective was not at all the standard until the late sixteenth century (Cinquecento). Before then many other systems were used, such that one would be justified in asking whether it would not be better to admit that different, parallel systems of perspective existed as late as the Renaissance. Since the norm was still to come, it was common to find painters and architects testing new methods that lay at the margins of linear perspective. As a result, there is no way to demonstrate that painters and architects as a whole were applying the rules of perspective from Brunelleschi’s time onward. Up until the end of the Cinquecento the word ‘perspective’ referred to a series of free and

uncoordinated systems, with debates being conducted in scholarly and artistic circles on the merits of each.¹

In Chap. 1 we will seek to define more clearly the similarities and differences between perspective and *perspectiva*, i.e., medieval optics. One of the main differences was the gradual trend to decouple linear perspective from medieval optics, the course of which included an entire chapter on the formation of binocular images.

Errors—Chap. 2 investigates the emergence of perspective as a geometric science and seeks to separate what is fact from what is fiction regarding the birth of perspective in Quattrocento Italy. Events that were codified into what may be regarded as the mythology of perspective are discussed, including Brunelleschi's untraceable *tavoletta*, Alberti's *costruzione legittima*, and the perspective in Masaccio's fresco of the *Holy Trinity* in the Church of Santa Maria Novella in Florence. This chapter will show how access to knowledge could change practices; it establishes, for instance, that the solutions found by draftsmen to the problem of how to draw the perspective view of a circle varied, depending on their degree of familiarity with optics and geometry. Chapter 3 provides a classification of the types of errors that may arise in perspective constructions, deepening our understanding of the problem by presenting several examples of works that depart from the rules of perspective. Chapter 4 scrutinizes a blatant example of mistaken judgment regarding the correctness of one specific case of perspective—the interpretation by Erwin Panofsky of Masaccio's *Trinity*. Although celebrated as a milestone in the history of perspective, this fresco is not a correct example of central perspective due to the many errors—both random and systematic—that can be found in its geometric construction. These results undermine the commonly held idea that linear perspective became the unspoken rule in Brunelleschi's time, with all other alternatives being gradually abandoned. Linear perspective was neither clearly defined nor followed as a general rule in these early stages, and there was not yet a sufficient consensus to limit alternative representational systems.

Theory—Chap. 5 outlines the theory of binocular vision presented by Ibn al-Haytham in *Kitāb al-manāẓir* and discusses the innovations and limitations of this medieval Arab scholar's work in the light of modern physiological optics. Chapter 6 seeks to retrace the impact of Ibn al-Haytham's theory on Latin medieval optics. There is evidence that the study of key sections of *Kitāb al-manāẓir* and the commentaries written by European scholars ensured the wide dissemination of his theory of binocular vision. Chapter 7 focuses on certain contemporary documents

¹The present book includes revised content from several papers, mostly in French, published in academic journals. Chap. 1: *Nel Segno di Masaccio*, ed. F. Camerota, Firenze, 2001, pp. 11–13. Chap. 2: *Les Espaces de l'homme*, eds. A. Berthoz and R. Recht, Paris, 2005, pp. 333–354. Chap. 3: *L'Hypothèse d'Oxford*, Paris, pp. 62–85. Chap. 4: *Nuncius* 17 (2003): 331–344. Chap. 5: *Arabic Sciences and Philosophy* 13 (2003): 79–99. Chap. 8: *Oriens/Occidens* 5 (2004): 93–131. Chap. 9: *Sciences et Techniques en Perspective* 2-1 (1998): 3–23. Chap. 10: *Zeitschrift für Kunstgeschichte* 67/4 (2004): 449–460. Chap. 11: *Physis* 45 (2008): 29–55. Appendix A: *L'Œuvre et l'artiste à l'épreuve de la perspective*, eds. M. Dalai Emiliani et al., Rome, 2006, pp. 411–430. The other parts of the book are new.

that explicitly condemned the practice of ‘two-point perspective.’ These texts, which were written by members of the earliest Italian academies and of the *Académie Royale de Peinture* in France, inform us that the theory and practice of monocular vision continued to encounter strong resistance during the Renaissance and well into the classical period.

Sifting the Hypotheses—Applying standard techniques of error analysis, Chap. 8 and Appendix 1 address the methodological issue of how to eliminate or reduce the errors that may be introduced during the *ex post* reconstruction of a perspective view. An in-depth analysis is presented of *The Saint Enthroned*, a fresco by Giusto de’ Menabuoi that illustrates the use of two-point perspective. The same methodology is then applied to 30 works produced in Italy between the Duecento and the Cinquecento in which the use of two-point perspective has been identified. The error analysis is supplemented by a reconstruction of the geometric plans and elevations in these paintings, working backward from the perspective views. This analysis based on a large number of works allows us to eliminate a series of alternative forms of representation, and the sifting of the different representational systems proves that binocular vision might have provided the foundations for the construction of these medieval and Renaissance perspectives.

However, the hypothesis that early works of perspective were constructed on the basis of binocular vision can be accepted only if all the competing assumptions are successfully rebutted. We therefore carried out an evaluation, one by one, of the various theses that currently dominate discussions of the history of perspective. In Chap. 9 we demonstrate the inconsistency on both logical and empirical grounds of the Hauck–Panofsky conjecture regarding ‘curvilinear perspective.’ Similarly in Chap. 10 we disprove the White–Carter conjecture regarding ‘synthetic perspective’ by pointing out a mathematical property that renders this system unlikely. Chapter 11 examines Andrés de Mesa Gisbert’s conjecture that medieval perspective was the result of an arithmetic method of construction, a solution that, while elegant, poses some serious difficulties.

All the competing assumptions having been disproved, I conclude that binocular vision and two-point perspective constituted a genuine alternative to linear perspective from the late Duecento onward. In this way a strong interdependence between optics and perspective is established that accords with the original meaning of the word *perspectiva* and opens up the possibility for a better understanding of how perspectives were constructed in the early modern period. I submit that binocular vision represents a key juncture point between the history of art and the history of science.²

²From this perspective, the binocular system makes a genuine difference with the foreshortening rule, which could have been derived from Euclid’s *Optica*, postulate 5, as well as from practical geometry, in particular the “*Turris altitudinem metiri*” section included in many treatises. See for instance Stephen K. Victor, *Practical Geometry in the High Middle Ages*, Philadelphia, 1979; Hubert L.L. Busard, “The ‘*Practica geometriae*’ of Dominicus de Clavasio,” *Archive for the History of Exact Sciences* 2 (1965): 520–575; and Cosimo Bartoli’s *Del modo di misurare*, Venezia, 1564.

The intent of this book is to explore the various explanations and past modes of rationalizing the phenomenon of vision that can be derived from the matrix of *Perspectiva*, thus contributing to the rewriting of an important chapter in the history of optics and perspective from an angle that takes into account the criticisms that have been brought to bear on linear perspective in the past, and that is more sensitive to the precarious balance that characterizes the early stages in any process of innovation.

I express gratitude to Lisa C. Chien, who translated several chapters from the French and diligently revised the whole text.

Saint-Martin
June 2015

Dominique Raynaud

Contents

1	Perspectiva Naturalis/Artificialis	1
1.1	Perspective in the Classification of the Sciences	2
1.2	The Phases in the Development of Optics	4
1.3	The Similarities Between <i>Perspectiva</i> and Perspective	5
1.4	The Differences Between <i>Perspectiva</i> and Perspective	9
 Part I Errors		
2	Knowledge and Beliefs Regarding Linear Perspective	15
2.1	The Myth of Perspective.	16
2.1.1	Filippo Brunelleschi	16
2.2	Perspective and Knowledge	23
2.2.1	Geometry and the Perspective of the Circle.	23
2.2.2	Optics and Binocular Vision	30
2.3	Conclusion	33
3	Understanding Errors in Perspective	37
3.1	The Classification of Errors	38
3.2	Methods of Foreshortening	39
3.2.1	Correct Foreshortening	41
3.2.2	Under-Foreshortening	41
3.2.3	Over-Foreshortening	44
3.3	Some Examples of Erroneous Foreshortening in Renaissance Painting	45
3.4	Conclusion	51
4	Fact and Fiction Regarding Masaccio's <i>Trinity</i> Fresco	53
4.1	Recent Research	54
4.2	The Construction of the Vault Ribs	58
4.3	Masaccio's Use of the So-Called <i>Costruzione Legittima</i>	61
4.4	The Determination of the Viewing Distance.	65
4.5	Conclusion	67

Part II Theory

5	Ibn al-Haytham on Binocular Vision	71
5.1	The Cases of Homonymous and Heteronymous Diplopia.	75
5.2	The Notion of Corresponding Points in Binocular Vision.	77
5.3	The Study of Physiological Diplopia (Experiments 1 and 2) . . .	79
5.4	The Determination of the Horopter (Experiments 3 and 4). . . .	80
5.4.1	The Theoretical Horopter.	81
5.4.2	The Experimental Horopter	86
5.5	Panum's Fusional Area (Experiment 5)	89
6	The Legacy of Ibn al-Haytham	95
6.1	The Availability of the Texts of Ibn al-Haytham in the West.	95
6.2	Obstacles to the Binocular Theory of Vision	101
6.2.1	Physiological and Pathological Diplopia	102
6.2.2	Diplopia Is not an Unusual Phenomenon.	103
6.2.3	Images Are not Blurred in Diplopia	104
6.2.4	Different Theories Regarding the Unification of Binocular Images	105
6.2.5	Neutralization Is not Constant	111
6.3	Conclusion	114
7	The Rejection of the Two-Point Perspective System	115
7.1	In the Earliest Italian Art Academies	116
7.1.1	Vignola and Danti (1559–1583)	116
7.1.2	Martino Bassi (1572).	121
7.2	In the Circles of the Académie Royale de Peinture	122
7.2.1	Grégoire Huret (1670).	122
7.2.2	Sébastien Le Clerc (1679).	124
7.3	Conclusion	129

Part III Sifting the Hypotheses

8	The Properties of Two-Point Perspective	133
8.1	Typical Constructions	135
8.2	Perspectives in Which the Spectator Is not Placed at Infinity	136
8.3	Perspectives that Differ from Linear Perspective.	137
8.3.1	Central Perspective	137
8.3.2	Bifocal Perspective	140
8.3.3	Trifocal Perspective	146
8.4	The Principles of Binocular Perspective	146
8.4.1	The Vantage Point and the Vanishing Point	146
8.4.2	Depth Gives Rise to Disparate Images	147
8.4.3	The Determination of the Fixation Point	149

8.4.4	The Crossing of the Orthogonals on the Axis <i>Communis</i>	151
8.4.5	Examination of the Plans and Elevations.	155
8.4.6	An Exploration of the Relationship $FF' \propto XP/HX$	155
8.5	Conclusion	158
9	The Hauck–Panofsky Conjecture Regarding Curvilinear Perspective	161
9.1	Compositions Based on a Vanishing Axis	164
9.1.1	The Basis of Panofsky’s Interpretation	165
9.1.2	The Limitations of Panofsky’s Interpretation	167
9.2	Our Methodological Approach	167
9.2.1	Errors in Panofsky’s Reconstruction	167
9.2.2	The Criteria Used to Test Panofsky’s Hypothesis	168
9.3	Analysis of a Corpus of Works	171
9.4	Conclusion	174
10	The White–Carter Conjecture on Synthetic Perspective	177
10.1	The Mathematical Properties of Synthetic Perspective	181
10.1.1	The Case of Linear Perspective	182
10.1.2	The Case of Synthetic Perspective	184
10.2	Conclusion	186
11	De Mesa’s Hypothesis Regarding the Arithmetic Construction of Perspective	191
11.1	The Arithmetic Construction Hypothesis	194
11.2	The Absence of Multiples or Submultiples of the Measurement Units	196
11.3	The Absence of Simple Proportional Ratios	203
11.4	The Length of the Operating Series	208
11.5	The Coincidence of Points at Infinity with Visible Loci	211
11.6	Reinterpreting Perspective Anomalies	212
	Conclusion	215
	Appendix A: Error Analysis and Perspective Reconstruction	225
	Appendix B: Catalogue of the Works	245
	Appendix C: Errors of Reconstruction	247
	Appendix D: Distance Between the Vanishing Points	249
	Appendix E: Plates	251
	Bibliography	267
	Index Nominum	283
	Index Rerum	289