Who Is the Founder of Psychophysics and Experimental Psychology?

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Abstract

The study is an investigation of the origins of psychophysics and experimental psychology. According to historians of psychology, Francis Bacon had the most crucial influence in the history of the experimental method, because he emphasized the importance of induction, skepticism, quantification, and observation. The present study, however, attempts to show that Ibn al-Haytham laid the foundations of the above aspects of the experimental method. Furthermore, a number of historians of psychology believe that Fechner was the founder of psychophysics with his application "Elements of Psychophysics" in 1860. This study shows that in the eleventh century, Ibn al-Haytham made an original contribution to the study of vision, wherein his psychophysics borrowed its structure from physics and its spirit from psychology. Several aspects of visual perception were investigated by him, including sensation (which occupies a central place in psychophysics), variations in sensitivity, perception of colors, sensation of touch, perception of darkness, the psychological explanation of moon illusion, and binocular vision. This study presents five experiments by Ibn al-Haytham regarding the errors of vision, which is called in contemporary psychology "visual illusion." These experiments have been applied and verified in Bahrain from both the physical and psychological perspectives. Finally, the study concludes that Ibn al-Haytham deserves the title "founder" of psychophysics as well as the "founder" of experimental psychology. In this respect, *Kitab al-Manazir* by Ibn al-Haytham, which appeared in the first half of the eleventh century, and not the "Elements of Psychophysics" by Fechner, which was published in the nineteenth century, marks the official "founding" of psychology, because it provides not only new concepts and theories but new methods of measurement in psychology.

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Bacon: The Founder of the Experimental Method

Historians of psychology agree that Francis Bacon had the most crucial impact on the development of the experimental method.[1] Before him, various groupings of experiments were carried out in the history of science; these include Peter Maricourt's *Industria Manuum* (it was Peter Peregrinus whom Roger Bacon referred to in *Opus Tertium* as *dominus experimentorum*), Thomas Aquinas's *Scientia Experientie* or its identical twin *Scientia Experimentalis*, and Nicolas of Cusa's *Experimenti Statici*. It is common knowledge that not only qualitative but quantitative experiments were already known in ancient times, in medicine, alchemy, and mechanics, among other departments of knowledge.[2] Science and scientific methods were valued as the best approach to any area of investigation. This trend culminated in the nineteenth century, when physics was seen as the queen of the sciences, and the more closely a discipline emulated physics, the greater the value placed on that disciplinary inquiry.[3]

The question of whether science uses a deductive or an inductive method has been around for a long time. The Aristotelian method was deductive, reasoning from the general to the particular. F. Bacon in his *Novum Organum* of 1620 sought to substitute induction.[4] He held that the method of science must be predominantly inductive, proceeding from the particular to the general. Moreover, he qualified his position by building in several critical elements for scientific inquiry. According to him the scientist must be skeptical and not accept formulations that cannot be tested through observation. Rather, the scientist must take a critical view of the world and proceed carefully with the study of observables. Bacon presented a strong statement of empiricism as the basis of science.[5]

According to F. Bacon, science should include no theories, no hypotheses, no mathematics, and no deduction, but should stay close to the fact of observation. He felt that anyone doing research with preconceived notions would tend to see nature in light of those preconceptions. F. Bacon trusted only the direct observation and recording of nature. With his radical empiricism, he made it clear that the ultimate authority in science is empirical observation.[6] In *Opus Tertium,* R. Bacon points out that mathematics "is the first of the sciences, without which the others cannot be known," that "the causes of natural things cannot be given except by means of geometry," and indeed that the Devil himself brought about the condemnation and neglect of mathematicians because without its service theology and philosophy are useless.[7]

All this seems to show that Francis Bacon explained induction, skepticism, quantification, and observation, while Roger Bacon explained the application of mathematics to optics; and all these led to the foundation of the experimental method. In fact, it was not R. Bacon or F. Bacon who pioneered these aspects of the scientific method but Ibn al-Haytham. R. Bacon was only a commentator on Ibn al-Haytham's writings on optics. Between the thirteenth and the seventeenth centuries, European books on vision were based on the Latin translation of Ibn al-Haytham's (known in Latin as Alhazen) *Book of Optics*. For instance, the writings on vision by R. Bacon (1210–1292) are largely commentaries on his writings. The same can be said of other European scholars such as Vittelo (1230–1270) and John Peckham (1240–1291), Archbishop of Canterbury.[8]

Roger Bacon did achieve considerable success in geometrizing optics. Faced with a variety of opinions on the applicability of mathematics to optics, he followed Ibn al-Haytham in giving mathematics maximum play — even while recognizing that there were problems beyond its reach.[9] Ibn al-Haytham's *Perspectiva* was R. Bacon's guide in his writings, which to a large extent constitute a commentary on Ibn al-Haytham's book. Bacon adopted the idea that only normally incident rays are effective, and he also accepted Ibn al-Haytham's psychological doctrine.[10] According to Bacon, that which is coming from the eyes does not mingle with that which comes from visible objects, because what comes from the eye is derived from an animated body and thus differs from what comes from an inanimate object. In this respect there is a regression in comparison with Ibn al-Haytham's theory.[11]

Boring was wrong; it was Ibn al-Haytham in the eleventh century not F. Bacon in the seventeenth century, who first introduced the notion that science must be inductive. Ibn al-Haytham wrote in *Maqala* (Book) I of *The Book of Optics* (*Kitab al-Manazir*):

> It follows from what we have stated and gathered by induction regarding distances that the distances from which an object can be perceived and those at which an object becomes invisible are according to the conditions and properties of the object itself, and also according to the strength or weakness of the sight itself that perceives it. Therefore, from all that we have stated and found by induction and experiment to be uniform and subject to no variation or contradiction, it is evident that sight does not perceive any object that exists with it in the same air and it is not perceived by reflection, unless that object combines the conditions we have stated, namely, that there exists between it and

> the eye a certain distance proportionate to that object; that it lies opposite the eye.[12]

A number of scientists agree that Ibn al-Haytham used mathematics and experimental observations in the arena of optics before any one else.[13] Throughout Book I of *The Book of Optics,*[14] he accurately employes the terms *experiment, examination, examiner, observer,* and *find* in his study of optics and visual perceptions. For example, he writes: "An accurate experimental examination of this fact" (p. 7); "When the instrument has been perfectly prepared and the experimenter wished to examine the perception of visible objects by sight" (p. 7); "Now when the observer looks at the visible object through the opening in the tube while the ruler lies between the eye and the object" (p. 8).

Sabra[15] argues that in *The Book of Optics* there appears for the first time a distinct concept of experiment consistently associated with three cognate words, *i'tabara, i'tibar,* and *mu'tabir*, which the Latin translation of the book rendered as *experimentare, experimentatio,* and *experimentator*, respectively. Sabra argued that the appearance of this concept of experiment, being essentially different from the Aristotelian and medical *emeiria* (almost always expressed in the Arabic literature by *tajriba*, experience), should be regarded not as a development within Aristotelianism or Galenism but as a "result of taking over into optics an idea [of testing] which had had an established career in astronomy." *I'tabara* occurs in the Qur'an (59:2) in the sense "to take heed or warning or example from past happenings," the sense frequently encountered in words of history or moral teaching, as, for example, in the title of Ibn Khaldun's famous book, *Kitab al-'Ibar*.

Thus, in the history of optics, the eleventh century marks a turning point from the classical metaphysical tradition to the beginnings of a coherent experimental and scientific approach. This was achieved by Ibn al-Haytham. His pioneering work in relating the physics of light to the anatomy of the eye created the science of physiological optics.[16] The following is the first optical experiment that he describes in detail in *The Book of Optics*:

> An accurate experimental examination of this fact may be easily made with the help of rulers and tubes. Let the experimenter who wishes to make such an examination proceed as follows. Take a very sound and straight ruler and draw along the middle of its surface a straight line parallel to its sides. Take a hollow cylindrical tube, very straight in

> length, perfectly round and ending in parallel circles; let its thickness be the same throughout and let it be fairly wide but not wider than the eye socket; draw on its outer surface a straight line extending from a point on the circumference of one base to the opposite point on the other side; and let this tube be a little shorter in length than the ruler. Divide the line along the middle of the ruler into three parts, and let the intermediate part be of the same length as the line on the surface of the tube; the remaining parts on either side may be of any length. Attach the tube to the surface of the ruler, placing the line on its exterior upon the intermediate segment of the line in the middle of the ruler's surface; and make sure that the ends of the tube coincide with the points marking off the middle segment. The tube should be so closely and firmly fastened so that it cannot be loosened or displaced.[17]

Sabra notes that Ibn Al-Haytham in *The Book of Optics* consistently eschews the term *tajriba*, the term corresponding to *empeiria* in the philosophical and medical literature with which he must have been thoroughly familiar, having himself made at one time summaries of many of Aristotle's and Galen's writings. (He appears to use *tajriba* in place of *i'tibar* at least once, in *On the Quality of Shadows*). According to Sabra, the experiments in *The Book of Optics*, or most of them, are essentially different in form from both the repeated experiences of the physicians and the "comparisons" of the astronomers. To operate explicitly with such a distinct concept of experimental proof while regularly attaching it to a definite set of terms (*i'tibar* and its cognate), and thus dissociating it from the idea of accumulated experience or *empeiria*, was a significant conceptual development in the history of experimental science.[18]

Ibn al-Haytham's *Optics* is a consistently mathematical and painstakingly empirical investigation of both light and vision. The hallmark of his unique style is his ability to resolve complex issues into closely interrelated series of experimental questions. Each specific problem is then subjected to a quantitative analysis of its variables under stringently controlled conditions. His series of experiments on the rectilinear propagation of light is a perfect illustration of his method. He uses a dark chamber with a small aperture in one wall to provide a point source of light. Filling the room with dust allows the beam of light to be both visualized and tested for linearity. Changing the atmosphere in the room (i.e., smoke instead of dust), gives the same result. Further checks are made using an inference procedure to disrupt the light beam. By this means he is able to show that light can only travel rectilinearly because the spot of light is only disrupted within a linear path; inference within curvilinear paths is ineffective. This use of the method of controlled observations is probably the first example of modern experimental design.[19]

His experiments with projected light images are of great importance for his hypotheses about vision and the eye. They provide us with what is, perhaps, the earliest version of the modern concept of conjugate points. In his implicit comparison of the eye with a pinhole camera, Ibn al-Haytham gives us the first modern synthesis of anatomy and optics. His conception of the eye as an optical system is best illustrated by his description of the lens and the optical axis of the eye.[20] To operate consciously and systematically with a concept of experiment as a distinct method of proof, and not merely to perform or refer to experiments, was no doubt a significant landmark in the history of experimental science.[21] Thus, during the eleventh century he associated psychology with physics or *ṭabi'a* and relied purely on scientific observation as a method of investigation. In this respect he was the real founder of the *i'tibar* or the experimental method in the history of science in general. This fact contradicts what most historians of psychology have written, giving the major credit to F. Bacon.

Fechner: The Founder of Psychophysics

Many historians of psychology consider Fechner to be the founder of psychophysics and thus the founder of quantitative psychology.[22] The publication in 1860 of Fechner's *Elemente der Psychophysik,* which was translated as *Elements of Psychophysics,* marks the official birth of the science of psychology.[23] It broadly contains the following topics: general considerations on the relation of body and mind, the concept and the task of psychophysics, a preliminary question, concepts concerning sensation and stimulus, the measure of physical activity, the principle of measurement for sensitivity, the principle of measurement for sensation, methods of measuring sensitivity, Weber's law, thresholds, further details on magnitude and relationship of the threshold in various sense domains, the parallel law in relation to Weber's law, and laws of the phenomena of mixture. According to Fechner himself, the first volume of the book contains the foundation of psychics measurement, that is to say, the establishment of its principle and the exposition of the methods, laws, and data which belong to its empirical proof. The second volume of the book developed the functions of psychic measurement together with their implications, which shift from the outer to the inner sphere in the mind-body relation.[24]

Fechner, the major proponent of psychophysics, also attempted to explore more fully the relationships between sensations and perception.[25] According to him, sensation depends on stimulation; a stronger sensation depends on a stronger stimulus; the stimulus, however, causes sensation only via the intermediate action of some internal process of the body. To the extent that lawful relationships between sensation and stimulus can be found, they must include lawful relationships between the stimulus and its inner physical activity, which obey the same general laws of interaction of bodily processes and thereby give us a basis for drawing general conclusions about the nature of this inner activity.[26]

By psychophysics, Fechner meant a theory which was new insofar as its formulation and treatment are concerned; in short, it was a theory of the relation of body and mind. As an exact science, psychophysics, like physics, must rest on experience and the mathematical connection of those empirical facts that demand a measure of what is experienced or, when such measure is not available, a search for it. Since the measure of physical magnitudes is already known, the first and main task of this work is to establish the as-yet-nonexistent measure of psychic magnitudes; the second is to take up the applications and detailed arguments that developed from it. The determination of a psychic measure is no mere matter of academic or philosophical abstraction but demands a broad empirical basis.[27] Psychophysics, already related to psychology and physics by name, must on the one hand be based on psychology and on the other hand give psychology a mathematical foundation. From physics outer psychophysics borrows aids and methodology; inner psychophysics leans more to physiology and anatomy, particularly of the nervous system, with which a certain acquaintance is presupposed.[28]

The empirical law that forms the foundation of the theory of psychological measurement was advanced long ago by various scholars in diverse areas and was formulated and experimentally proven in relative generality, particularly by Weber, who, in Fechner's opinion really should be called the father of psychophysics. In addition, the mathematical functions that constitute the most general and most important applications of Fechner's principle of measurement were laid down long ago by various mathematicians, physicists, and philosophers, such as Bernoulli (Laplace, Poisson), Euler (Herbart, Drobisch), and Steinheil (Pogson), and are based on special cases that were particularly suited to psychophysics and are reproduced and accepted by other scholars.[29] With regard to the manner in which mathematics has been introduced into this work, Fechner wished his writing to be regarded by mathematicians as if written for nonmathematicians, and by nonmathematicians as if written for mathematicians.[30]

Fechner developed the method of average error (also called the method of adjustment). It consists in having subjects adjust a variable stimulus until they perceive it to be equal to a consistent standard stimulus.[31] Fechner's stress on invariance, his operational approach to measurement, and his employment of hypothetical constructs are examples of how close he was to modern modes of dealing with these problems. Elsewhere his work foreshadowed theoretical positions that inevitably strike the current reader as belonging to contemporary psychological theory. In volume 1, he took the first steps toward a quantitative psychology and staked his claim to his being the "father of psychophysics" and the pioneer experimental psychologist. He brought to scientists and scholars, for the first time, the methods of psychological measurement that still remain the basis of psychophysics, although these procedures are now supplemented by others. These methods were employed to fulfill Fechner's goal of an objective psychology as laid out in 1851 in *Zend-Avesta*.[32]

If Fechner founded experimental psychology, he did it incidentally and involuntarily, and yet it is hard to see how the new psychology could advance as it did without an *Element der Psychophysik* in 1860.[33]

> If mathematical psychology is possible, it must be founded on the basis of material phenomena that underlie the psychical, because they allow a direct mathematical approach and definite measurement, as is not true with respect to the psychical. There is nothing, however, to stop us from considering the materialistic phenomena that underlie a given psychic event as a function of the psychic event and vice versa.[34]

Such an empirical and quantitative program was to replace one that had been primarily speculative and philosophical. By 1860, Fechner had brought together a considerable body of experimental work, his own and that of others, to support his thesis.[35]

Fechner's claim to greatness within psychology does not, however, derive from these psychological conceptions of his, nor even from the formulation of his famous law. The great thing that he accomplished was a new kind of measurement. The critics may debate the question as to what it was that he measured; the fact stands that he conceived, developed, and established new methods of measurement, and that, whatever interpretation may later be made of their products, these methods are essentially the first methods of mental measurement and thus the beginning of quantitative experimental psychology. Moreover, the methods have stood the test of time. They have proven applicable to all sorts of psychological problems and situations that Fechner never dreamed of, and they are all still used with only minor modifications in the greater part of quantitative work in the psychological laboratory today.[36]

Thus, historians of psychology agree that Fechner with his publication in 1860 of *Elements of Psychophysics* marks the starting point of experimental psychology.[37] He is seen as the founder of psychophysics and experimental psychology. He was the first scientist to give psychology a mathematical foundation, and he took the first steps toward a quantitative psychology. In this part of the study, however, we are going to introduce a new view on the history of psychology, that Ibn al-Haytham with *The Book of Optics*, and not Fechner, was the founder of psychophysics and experimental psychology. According to Sabra, Ibn al-Haytham's views have been almost totally neglected by historians, and, it seems, for the same reason, historians of philosophy, who are concerned with the history of perception, have usually regarded works on optics as scientific or mathematical and therefore falling outside their domain, whereas historians of science and mathematics have tended to ignore the psychological sections in such works as properly belonging to philosophy. Even historians of optics, who have given attention to Ibn al-Haytham's doctrine of vision, appear for the most part to have assumed that it was feasible to elucidate the account presented in Book I of *The Book of Optics* without exploring the subsequent account on perception, as if the two could be meaningfully divorced from one another.[38]

The area into which psychologists study the link between variation in physical dimension and psychological dimension is called *psychophysics*, and the methodology used to describe this link is termed *experimental psychology*. This description of psychophysics is found in Books II and III of *The Book of Optics* by Ibn al-Haytham. My aim is simply to present *The Book of Optics* as I understand it, therein justifying my belief that it laid the foundation of psychophysics and experimental psychology.

The Book of Optics by Ibn al-Haytham

Latin manuscripts of Ibn al-Haytham's *The Book of Optics* had rendered the author's name in various forms, for example, Alhacen filius Alhaycan, Hacen filius Hucayn filius Haycen, and Achen filius Hucayn filius Aycen.[39] In the twelfth century, *The Book of Optics* was translated into Latin with the name *Perspectiva*. In 1572, Risner produced the *Opticae Thesaurus*. This was the first printed version of Alhazen's book with added titles and annotations from Vitello's *Perspectiva*.[40] Risner found in the two manuscripts he used for his edition that the author's name was rendered as Alhazen, which obviously corresponds to Ibn al-Haytham's first name, al-Hasan. In the early 1900s, copies of *The Book of Optics* were found in manuscript collections in Istanbul. Krause published a complete list of these manuscript copies in 1936. In 1942, Mustafa Nazif published the first substantial study of Ibn al-Haytham's optical work based directly on original manuscripts. The first volume, which has the Arabic text of Books I–III, was published in 1983 by the National Council for Culture, Arts, and Letters in Kuwait. *The Book of Optics* was translated with an introduction, commentary, glossaries, concordance, and indices by Sabra of Harvard University in 1989.[41] All citations in the present study are taken from Sabra's excellent translation.

According to Ibn Abi Usaybi'a's *Tabaqat*, Ibn al-Haytham's writings include fourteen works wholly devoted to the subject of light and vision, a clear indication of their author's strong and sustained interest in optical matters.[42] These writings are (1) *Kitab lakhkhastu fihi 'ilm al-manazir min kitabay Uqlidis wa Batlamyus, wa tammamtuhu bi ma'ani al-maqala al-ula al-mafquda min kitab Batlamyus* (A book in which I have summarized the science of optics from the two books of Euclid and Ptolemy, to which I have added the notions of the first discourse which is missing from Ptolemy's book); (2) *Maqala fi al-maraya al-muhriq, mufrada 'amma dhakartuhu min dhalik fi talkis kitabay Uqlidis wa Batlamyus fi al-manazir* (Treatise on burning mirrors, which is separate from what I have stated on this subject in the summary of the two books of Euclid and Ptolemy on optics); (3) *Kitab al-manazir* (Book of optics); (4) *Maqala fi daw al-qamar* (Treatise on the light of the moon); (5) *Maqala fi qwa' quzah wa al-hala* (Treatise on the rainbow and the halo); (6) *Maqala fi ru'yat al-kawakib* (Treatise on the appearance of the stars, or On seeing the stars); (7) *Maqala fi al-maraya al-muhriqa bi al-dawa'ir* (Treatise on spherical burning mirrors); (8) *Maqala fi al-manazir 'ala tariqat Batlamyus* (Treatise on optics according to Ptolemy's method); (9) *Maqala fi kayfiyyat al-azlal* (Treatise on the quality of shadows); (10) *Maqala fi adwa' al-kawakib* (Treatise on the light of the stars); (11) *Maqala fi al-athar alladhi fi wajh al-qamar* (Treatise on the mark on the face of the Moon); (12) *Maqala (or qawl) fi al-daw* (Discourse on light); (13) *Maqala fi al-kura al-muhriqa* (Treatise on the burning sphere); and (14) *Maqala fi surat al-kusuf* (Treatise on the form of the eclipse).

These publications show clearly his expertise in this domain of science. He was quite familiar with earlier works on the subject, such as those of Euclid and Ptolemy. But he was not a translator or commentator on the previous literature; he made an original contribution to the field. His writings also show how psychophysics and experimental psychology relied on the solid base of investigations in astronomy. This result shows that psychophysics borrowed its structure from physics and its spirit from psychology in the eleventh century.[43]

The Book of Optics of Ibn Al-Haytham is divided into seven books. Book I shows the manner of vision generally, Book II details the visible properties, Book III examines the errors of vision and their causes, Book IV studies visual perception by refraction from smooth bodies, Book V shows the positions of images, Book VI examines visual errors by reflection and their causes, and Book VII studies the manner of visual perception by refraction through transparent bodies whose transparency differs from that of air. Book I is titled "On the Manner of Vision in General" and consists of eight chapters: "Preface to the book," "Inquiry into the Properties of Sight," "Inquiry into the Properties of Lights and into the Manner of Radiation of Lights," "On the Effect of Light upon Sight," "On the Structure of the Eye," "On the Manner of Vision," "On the Utilities of the Instruments of Sight," "On the Reasons for the Conditions Without the Combination of Which Vision Is Not Effected." In the introduction to Book I, he summarizes and reviews the literature on previous research in optics. He notes:

> Early investigators diligently pursued the inquiry into the manner of visual sensation and applied their thoughts and effort to it, eventually reaching the limit to which their investigation had led, and gaining as much knowledge of this matter as their inquiry and judgment had yielded. Nevertheless, their views on the nature of vision are divergent and their doctrines regarding the manner of sensation not concordant. Thus, perplexity prevails, certainty is hard to come by, and there is no assurance of attaining the object of inquiry. How strong, in addition to all this, is the excuse for the truth to be confused, and how manifest is

> the proof that certainty is difficult to achieve! For the truths are obscure, the end hidden, the doubts manifold, the minds turbid, the reasoning various; the premises are gleaned from the senses, and the senses (which are our tools) are not immune from error.[44]

He concluded Book I with the following remarks:

> We have shown the reasons on account of which the eye cannot perceive any visible object unless the object combines the conditions stated. The preceding chapters and the explanations we have given in them are what we intended to make manifest in this book.[45]

Ibn al-Haytham distinguishes two main approaches to the study of vision, which he ascribes to "physicists" (or natural philosophers, *ashab al-tabi'a*) and to "mathematicians" (*ashab al-ta'alim*). The first of these approaches seeks to account for visual perception in terms of "forms" received in the eye, and the second explains the visible appearance of objects by means of "visual rays" assumed to go forth from the eye. In Ibn al-Haytham's view, neither approach is self-sufficient, though each captures a certain amount of the truth. Accordingly, he became convinced that a sound and complete theory of vision must bring these two approaches together or, as he puts it, must achieve a "synthesis" (*tarkib*) of physical and mathematical considerations. As a first approximation, the synthesis proposed by Ibn al-Haytham in the *Optics* can be described as an application of the geometrical methods employed by the visual-ray theories to the "physical" doctrine of forms.[46] Ibn al-Haytham writes:

> Our subject is obscure and the way leading to knowledge of its nature difficult; moreover, our inquiry requires a combination of the natural and the mathematical sciences. It is dependent on the natural sciences because vision is one of the senses and these belong to natural things. It is dependent on the mathematical sciences because sight perceives shape, position, magnitude, movement and rest, in addition to its being characterized by straight lines; and since it is the mathematical sciences that investigate these things, the inquiry into our subject truly combines the natural and the mathematical sciences.[47]

Book II, "On the Visible Properties, Their Causes and the Manner of Their Perception," consists of four chapters: "Preface," "On Distinguishing the Lines of the Ray, "On the Manner of Perceiving Each of the Particular Visible Properties," and "On How Sight Perceives Visible Objects." Chapter 2, in particular, tackles various issues related to the psychophysics of vision or perception: perception of light, of color, of distance, of position, of solidity, of shape, of size, of separation, of continuity, of number, of motion, of rest, of roughness, of smoothness, of transparency, of opacity, of shadow, of darkness, of beauty, of ugliness, of similarity, and of dissimilarity. In Book II, Ibn al-Haytham discusses the different conditions of the radial lines and distinguishes their characteristics. In addition, he gives a detailed account of all aspects of visual perception, shows the manner in which sight perceives each of them, distinguishes the ways in which sight perceives visible objects, and shows how they differ from one another.[48]

In Book II of *The Book of Optics*, Ibn al-Haytham maintains that the objection raised by the adherents of the visual-ray hypothesis applies only to a deficient theory, not to a properly developed one that takes into account the psychological process necessarily involved in every normal act of seeing. Accordingly, the purpose of Book II is to provide a full explanation of the psychology of visual perception — undoubtedly the most important single component of the theory of direct vision already launched in Book I. The general outline of the psychological account is as simple as it is distinctive. An image (or form) of the object seen is carried intact from the eye in which it has been received to the "common nerve" where it is perceived by a faculty called "the last sentient" (*al-hass al-akhir*), which resides in the front of the brain. Presumably this is where all kinds of sensation (visual, auditory, tactile) are registered after they have been delivered by the various sense organs.[49]

Book III, "On Errors of Direct Vision and Their Causes," consists of seven chapters: "Preface," "On What Needs to Be Advanced for Clarifying the Discussion of Errors of Sight, "On the Causes of Errors of Sight, "On Distinguishing Errors of Sight," "On the Ways in Which Sight Errs in Recognition," and "On the Ways in Which Sight Errs in Inference." Chapter 7 tackles several issues related to the psychology of visual error, in current psychological terms "visual illusions." These issues are errors of distance, position, illumination, size, opacity, transparency, duration of perception, and the condition of the eye. As far as the theory of direct or rectilinear vision is concerned, Ibn al-Haytham's fundamentally new ideas, according to Sabra, are mostly contained in the first two books of *The Book of Optics*. The third book is largely an exercise in the extension and application of these ideas. But the applications often seem somewhat mechanical or only a little inspired; and they frequently serve to illustrate obvious remarks, rather than explore new ground.[50] Book III is an experimental proof of Ibn al-Haytham's theory of vision and perception. As he puts it: "We will now explain in detail and sum it up, and also show how these matters can be experimentally examined in such a way as to achieve certainty."[51]

Psychophysicists have tackled various issues including sensitivity to light and light intensity, general sensation and its variation, perception of color, the sensation of touch, perception of darkness, the moon illusion, and binocular vision. Regarding sensation, Ibn al-Haytham writes:

> It has also been shown that sensation occurs only through the crystalline. Therefore, the eye's sensation of the light and color that are on the surface of the visible object occurs only through that part of the crystalline's surface which is determined by the cone formed between the object and the center of the eye. And we saw that this humor has some transparency and some density, and for this reason it is likened to ice. Thus, because it is somewhat transparent it receives the forms and these pass through it on account of the transparency that is in it; and because it is somewhat dense it resists the forms and hinders them from passing throughout it on account of that density that is in it, and the forms are fixed in its surface and its body on account of that density. Similarly, with every transparent body that is somewhat dense: when it is illuminated, the light passes through it according to the transparency that is in it, and the light is fixed on its surface according to its density; thus light appears on the surface and in the whole of the body in as much as it is fixed in it.[52]

Ibn al-Haytham does not identify physiology and psychology, nor does he take the seeing of an object to be merely a matter of holding up an image to the mind's eye, so to speak. To present his theory simply as an explanation of how an optical image flows through the visual apparatus would be to concentrate on the results of Book I of his *Optics*, and to disregard those of the two following books. He was fully aware that we see things, not images, and he insisted on the distinction between sensation and perception, although he applied the same word, *idrak* (comprehension/perception) to both, calling the former "perception by pure sensation" (*idrak bi-mujarrad al-hiss* or *comprehensio solo sensu*). Book II, in fact, expounds an elaborate theory of what we should call "visual perception." The theory involves the notion of form as the total visible appearance of a thing or the totality of the thing's visible characteristics. The "form of an object," in this sense, is made up of all the object's "visible properties" (*al-ma'ani al-musara*), as he calls them.[53] Regarding touch, he writes:

> Now the sensation of touch and of pain extends from the organs only through the filaments of the nerve and through the spirit extending within those filaments. So when the forms of visible objects occur in the body of the vitreous humor and are sensed by this organ, the sensation extends from it into the sentient body that fills the cavity of the nerves that joins the eye and the front of the brain. The form extends, along with the extension of the sensation, while preserving the arrangement of its structure and the relative positions of its parts. For it is in the nature of the sentient body to preserve the arrangement of these forms. And this arrangement is preserved in the sentient body because the parts of this body that receive the parts of the forms, and the distribution of the receptive power that exists in the parts of the sentient body, are similarly arranged in the vitreous body and throughout the subtle body that fills the nerve's cavity. That being so, when a form arrives at any point on the surface of the vitreous, it runs along a continuous line the position of which remains untouched in the nerve's cavity through which the sentient body extends.[54]

Ibn al-Haytham's description of the unconscious processes that underline our perception of the physical world are not confined to considerations of features internal to the optical image, but include other experiences, not all of which are connected to the organ of sight. Tactile and muscular sensations that do relate to the organ of sight are, for example, those experiences of opening and closing our eyes, which, he says, are at the basis of our judgement that objects of vision lie before us in external space and not inside our eyes or our heads. Another example is the muscular sensation associated with turning the head or orienting the eyeball, which is involved in judgements about direction. Other examples involve other types of experience. Some of the most remarkable explanations in this connection are concerned with estimating the distance of an object, itself an essential factor in estimating the object's size.[55]

Fechner, according to Schultz, developed the method of average error in the nineteenth century.[56] Ibn al-Haytham asked why objects very close to the eye appear to be larger than they are. Vision estimates the size of a visible object by comparing the angle subtended by the object at the center of the eye with the estimated distance of the object. In all cases, the distance that sight is capable of estimating is that between the surface of the eye and the object, and this falls short of the "real" distance by an amount equal to the radius of the eyeball. For moderately remote objects, the difference between the real and the estimated distance is negligible. The difference becomes critical when the distance of the object from the surface of the eye is less than, equal to, or not much larger than the radius of the eye. In this case the comparison is made between a large angle and an estimated distance appreciably smaller than the real one.[57]

Saturation is a psychophysical quality of light that might be described as the degree to which a color appears to be free of whiteness or blackness or the extent to which it is colored as opposed to achromatic. Although many variables can affect saturation (for example, intensity, retinal locus of stimulation, stimulus size, temporal factors), the two most important determinants are colorimetric purity and wavelength.[58] Regarding saturation of colors, Ibn al-Haytham writes:

> Now to distinguish between two greens is not the same as the sensation of green, for the latter is due to the eye's becoming green by the action of the green, and the eye has become green by the action of the two greens; and as a result of becoming green by the action of both greens the sense perceives them to be of the same kind. Thus its perception that one of the greens is stronger than the other, and that they are of the same kind, is a discernment of the coloration that has taken place in the eye, and not a sensation of the coloration itself. Similarly, when two colors are of similar strength and of the same kind, the sense will perceive them and perceive that they are of the same kind and of similar strength. And it is similarly the case with lights in regard to the sense of sight. For the sense of sight perceives the lights, differentiates between strong and weak lights and perceives their similarity in strength and weakness. Therefore, the sense of sight's perception of the similarity and dissimilarity of colors and lights, and its perception of the similarity and dissimilarity of the outlines and structures of the forms of visible objects, is not due to mere sensation but to their being discerned and compared with one another.[59]

According to Fechner, a lengthy stay in the dark gives one the capacity to see in the dark; by staying in the light for a time one loses this ability. But what does it mean, to see in the dark? It means that one can still distinguish from darkness a light, which photometrically differs very little from the dark night. Indeed, we have to consider here not so much an absolute sensation as a difference, since the nocturnal darkness still has its own photometric intensity. Thus it appears as if the tiring of the eye by the stimulation of light also blunts its sensitivity for differences.[60] Ibn al-Haytham notes this clearly in Book II of *The Book of Optics*, in his view of the perception of darkness:

> As for darkness, sight perceives it by inference from the absence of light. For darkness is the total absence of light. Where, therefore, sight perceives a certain place without perceiving any light in it, it will sense darkness. Darkness is perceived by the sentient from lack of sensation of light.[61]

Regarding the perception of motion, Fechner argues:

> When two impressions arrive too quickly one after the other, they fuse into one uniform sensation, and one might ask how great the interval between them would have to be, so that they could still be perceived as distinct. One cannot give a purely experimental answer to this question for reasons analogous to those which apply to other thresholds of space perception, for each impression leaves an aftereffect, just as each impression is surrounded by an irradiation circle. If this aftereffect of the first impression is still strong enough when the second one does not reach the differential threshold of intensity, then one impression must uniformly fuse with another.[62]

Motion requires a directional component in either its stimulus or its percept. This directional component makes motion different from other forms of spatio-temporal modulation. The proximal stimulus for the vast majority of motion experiences is some corresponding movement of the retinal image.[63] This correspondence has led some students of perception to explain motion perception in terms of various physical correlates in the stimulus.[64]

The detection of movement is a primary function of virtually every sort of visual system, and it has obvious biological utility. But, detection of movement, or even of relative velocities, is not sufficient to account for the way we perceive the environment as a stable frame of reference within which we orientate ourselves, in which we move, and in which other objects are observed to be in motion: We must account for the ability to discriminate between the visual effects of self-produced movement and the visual effects of other forms of motion in the environment.[65] Again quoting Ibn al-Haytham:

> As for motion, sight perceives it by inference from comparing the moving object with other visible objects. For when sight perceives a moving object together with other visible objects, it perceives the position of the object in relation to the others and its alignment with them. If the object is moving, but those objects do not share in the same motion, then the position of that object will vary in relation to

> those objects while in motion. And if sight perceives it together with those objects and perceives its position with respect to them, then it will perceive the object's motion. Sight therefore perceives motion by perceiving the varying position of the moving object in relation to other objects. Sight perceives motion in one of three ways: by comparing the moving object with other objects, or with a single object, or with the eye itself.[66]

That celestial magnitudes appear larger at the horizon than at higher altitudes is a commonly known phenomenon that has been recorded and investigated since antiquity. Because the phenomenon is particularly noticeable in the case of the moon, it has sometimes been referred to in recent times as the "moon illusion," a designation also reflecting the accepted understanding of the apparent enlargement as a psychological effect. Ibn al-Haytham freed himself from the erroneous view in the *Almagest* and, setting off from a new level of understanding some of the elements of which he found in Ptolemy's *Optica*, he offered in his *Book of Optics* psychological explanations in terms of what modern psychologists have called, with some exaggeration, the size-distance constancy principle.[67]

The moon illusion refers to the phenomenon that the moon appears larger when it is viewed at the horizon than at the zenith, although the projected images in both cases are identical. In fact, the moon occupies a far smaller fraction of the visible sky than most individuals assume.[68] Boring proposed that the apparent size of the moon is affected by the angle of the eyes relative to the head.[69] That is, the moon illusion is produced by changes in the position of the eyes in the head accompanying changes in the angle of elevation of the moon. He concluded that the moon illusion depends on raising or lowering the eyes with respect to the head. Mere movements of the neck, head, and body are not causal factors. There is, however, no convincing psychological process to explain Boring's general findings.[70] He stated in 1943 that there is no satisfactory theory for explaining this phenomenon. It is not due to physical causes outside the visual mechanism. It is not due to the greater brightness of the moon in elevation, when atmospheric haze is diminished. It depends on raising or lowering the eyes. Movements of the head, neck, and body do not cause it.

Ibn al-Haytham offered his psychological explanation of the moon illusion at the end of the last chapter in Book VII of his *Optics*, a chapter devoted to the "errors of sight" due to refraction.[71] He wrote that sight perceives any star at the zenith to be smaller than in any region of the sky through which the star travels; that the farther the star is from the zenith the larger its magnitude will appear; that the star looks largest at the horizon; and that the same is true of the intervals between the stars. Now this is found to be so in fact, namely, that the stars, and their mutual distances, appear to be smaller in the middle of the sky than when they are far from it, and that the star (or interval between two stars) appears largest at the horizon. Why this is so remains to be shown. In Book II in the discussion of size, it is shown that sight perceives size from the magnitude of the angles subtended at the center of the eye and from the magnitudes of the distances of the visible objects and from comparing the magnitudes of the angles to those of distances.[72]

Perhaps the most remarkable series of neglected theories and discoveries in Ibn al-Haytham's book are those concerning binocular vision, which are set out in chapter 2 of Book III. His ideas on how the optic nerves combine in the optic chiasma are described in Book I and are derived from Galen. These ideas have been well cited; however, Howard and Rogers found no reference to the ideas on binocular vision contained in Book III, and most of these ideas were not described again until the nineteenth century.[73] Ibn al-Haytham mentions that an object appears double when one eye is pushed by the finger and, as Galen pointed out, when the visual axes converge on the object of interest. Ibn al-Haytham writes:

> When one eye moves for the purpose of vision, the other eye moves for the same purpose and with the same motion; and when one of them comes to rest, the other is at rest.[74]

Hering cited Ibn al-Haytham on this point, which is now referred to as Hering's Law of Equal Innervation.[75]

In contemporary psychology, eye movements are classified in a number of ways, depending upon the kinds of analyses being made. We can separate those that are voluntary from those that are involuntary; those in which the eyes move in the socket from those in which the entire head moves; those that result in large displacements of the retinal image from those that result in small displacements; and those in which the two eyes move in parallel from those in which they move in opposition. When the eye is stationary and oriented straight ahead the three sets of muscles are under tension, each member of a pair in balance with its opposite. When a movement occurs along any one of these planes, one member of the pair contracts while the other relaxes.[76]

Ibn al-Haytham verified experimentally his theory of binocular vision, which involved two eyes.[77] There can be no doubt, however, about the importance of Book III for the history of the psychology of vision, if only because of the large amount of material it contains and the experimental and, apparently, original concepts around which this material is organized.[78] The experimental examination in these paragraphs consists of five experiments carried out by Ibn al-Haytham.

Experiments

Experiment 1

With both eyes focused on the object at K, the point in which the common axis EZ cuts the transverse line HT at right angles:

1. The two objects at H and T, and all points on HT, are seen single; the line HT appears as a single line; and
2. The line EZ is seen as two lines that intersect at K, and so is each of the diameters AD and BG.

Experiment 2

With the eye fixed on the object at H or at T — a case in which the visual axes are not symmetrically situated with respect to the common axis EZ:

1. The objects at H, K, T, and all points on HT, are seen single; the line HT appears as a single line; and
2. The line EZ, and each of the diameters AD and BG, are seen double.

Experiment 3

With two objects at L and F on the common axis EZ (=c), before and after K, respectively, and with the eyes focused on K:

1. The two objects appear as four — two over to the right, and two over to the left; and
2. Each of the four objects (i.e., images) appears on one of the two lines into which c has been doubled.

Experiment 4

Three cases are considered:

1. With the eyes fixed on K and objects O_1 and O_2 placed at two points on one of the diameters, then on the other, one object, O_1, before, and the other, O_2, beyond K: Each of the two objects, and each of the diameters, appears double.

2. With the eyes fixed on K, and the objects O_1 and O_2 placed on the near segments of the diameters: The two objects appear as four — two closer together, and two farther apart.
3. With the eyes fixed on K, and the two objects placed on the far segments of the diameters: The two objects appear as four, as in case (2), two closer together and two farther apart.

Experiment 5

The eyes are fixed on the middle object at K while regarding an object placed, first, at a point I beyond H but very close to it, then at a point Q farther away from H — both I and Q being on the right edge of the board: The object appears single when regarded at I, and double when regarded at Q.

Conclusion

According to Ibn al-Haytham:

> From the experimental examination of the conditions of the diameters on the board and of the objects fixed on them at points other than the middle, it is manifest that every object lying on the common axis and perceived by means of the radial axis will appear in its own place, where perception of it is acquired with one eye and one visual axis or with both eyes and both axis. It is manifest, moreover, that every object perceived by one eye and by means of the radial axis, but which does not lie on the common axis, will appear at a place closer to the common axis than its true place. The same also holds for what is perceived through rays other than the axis; for if sight perceives an object as it is, and the form of that object occurs at a single place in the cavity of the common nerve, so that the parts of it are joined together in the way they are in the object.[79]

In reviewing Ibn al-Haytham's visual physiology with the advantage of almost a thousand years' hindsight, his achievements are still impressive. Virtually single-handedly he created the foundations of modern physiological optics, an accomplishment which is astonishing considering the severe technological limitations of his period. Much more important than these achievements, however, is his remarkable insight into the method of modern scientific inquiry. His experiments on the rectilinear propagation of light document this new approach. Furthermore, his belief that experimental observation alone is the final arbiter of the truth of scientific theory is his most original contribution. For example, when he observed that objects are seen both by perpendicular and by incidental rays, he modified his view on the central role of perpendicular rays in vision even though it meant abandoning his theory of an upright image in the eye. It is as the pioneer of empiricism that Ibn al-Haytham made his most significant contributions to the neurosciences.[80]

According to Sabra, Ibn al-Haytham was the first and foremost mathematician who was contributing to what he consciously conceived as a "physico-mathematical" project; and while his discussions of visual illusions may be said to have epistemological implications, his treatment of them is clearly the work of one who wrote as an experimental psychologist and not as an epistemologist.[81] Sabra concludes:

> The experimental orientation of Ibn al-Haytham's concepts and procedures is unmistakable. With the addition of measurement, Book III would have been indistinguishable in character from a modern book in experimental psychology.[82]

If Ibn al-Haytham had lived for another ten years, he may have written an eighth and ninth chapter of *The Book of Optics* titled "Psychophysics" and "Experimental Psychology," combining psychology with physics, or the mind with the body.

Khaleefa and Manaa[83] from the University of Bahrain have carried out an empirical study regarding Ibn al-Haytham's previously summarized experiments. Their study discovered the existence of an *i'tibar* which they titled "Ibn al-Haytham Scale for the Error of Vision" (IHSEV), which dates back to the eleventh century. The study shows that Boring, the well-known historian of psychology, had attempted to conquer by his treatise "A History of Experimental Psychology," a theoretical Mount Everest. Boring asks: How did experimental psychology — scientific psychology — come into being and what is it's nature? First, there is the Renaissance, and then the emergence of science, with the names of Copernicus (1543), Kepler (1609), Galileo (1638), and finally Newton (1687) standing out. Vision was the best understood of the five senses. Newton's *Optics* (1704) is no doubt responsible for it. Not only did this book and subsequent work of the physicists render a fairly complete knowledge of the laws of refraction and of optical instruments available for application to the problem of the eye, but it is also true that the *Optics*, especially in respect to color, contributed some incidental psychological information.[84]

The Khaleefa and Manaa study shows that Ibn al-Haytham actually put forward the basis of the experimental method in his well-known encyclopedia *The Book of Optics* and that numerous Latin translations of the book were to have a profound influence on the history of science up until the seventeenth century. In addition to this, the study presents the contribution of psychophysicists in the West such as Weber, Fechner, and Helmoholtz, who engaged in one important aspect of their early experimentation with vision. As early as the eleventh century, Ibn al-Haytham was the first scientist who experimentally investigated and formulated a theory of vision, visual perception, and the error of vision. Their empirical study shows that Ibn al-Haytham rigorously followed the scientific experimental method in his marvelous study of the error of vision. The renewed IHSEV has been applied to a sample of 235 participants from Bahrain, who were selected with respect to gender, age, and educational level. Some procedures were adapted in the application of the renewed scale. The most remarkable finding of Khaleefa and Manaa's study is the concordance of their findings with Ibn al-Haytham's *i'tibar* (method) by 78 percent. According to the complexity of the study as based on Ibn al-Hayham's *Optics*, their findings are explained from a number of dimensions, including visual geometry, physiological physics, and psychology.

The question in the present study is this: Who is the "founder" of psychophysics and experimental psychology? Boring described "founding" in these terms:

> When the central ideas are all born, some promoter takes them in hand, organizes them, adding whatever else seems to be essential, publishes and advertises them, insists upon them, and in short "founds" a school.[85]

Thus, "founding" is quite different from originating, though we need not make the distinction a disparaging one. Both originators and founders are essential to the formation of a science, as indispensable as are the architect and the builder in constructing a house.[86] Taha concluded, "It can safely be said that Ibn al-Haytham is the founder of the psychology of vision"[87] and "modern psychophysics."[88] It is our conclusion that Ibn al-Haytham deserves the full title of Founder of Psychophysics as well as Founder of Experimental Psychology. *The Book of Optics* by Ibn al-Haytham in the first half of the eleventh century, and not the *Elements of Psychophysics* by Fechner in the nineteenth century, marks the official "founding" of psychology because it provides not only new concepts and theories, but new methods of measurement in psychology.

Notes

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4. Boring, *A History of Experimental Psychology*, 13.

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17. Ibn al-Haytham, *The Optics*, 7.

18. Sabra, Introduction, commentary, glossaries, concordance, indices of *The Optics* of Ibn al-Haytham, vol. 11, 18.

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48. Ibid., 113.
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