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Introduction

The Context for Perception

The scientific study of perception is the study of the qualities of experience and the conditions under which they occur. Although Gestalt psychologist Kurt Koffka (1935) set the scientific goal of explaining why the world *looks* as it does, his treatment of many other dimensions of consciousness, ranging from sound localization to cognition, indicated that there is in principle no reason why perception scientists should not also study all forms of experience, including the aesthetic experiences as well as pain. In fact, the discipline of perception is as broad as the states and varieties of consciousness itself.

Nevertheless, there are several reasons why the scientific study of visual experience preceded, and also seems to predominate, the study of other modalities of consciousness. First is the rule of scholarly inertia. Vision and visual perception have been studied for more than 2500 years (Wade, 1998), as a result of the Ancient Greeks' interests in astronomy and optics and to the subsequent realization that the eye could be treated as an optical instrument (Boring, 1950). Therefore, it continues to be studied simply because it has proved itself to be a valid and significant body of knowledge. Of course, the Ancient Greeks did not discover science or the empirical approaches to knowledge that require nature to be not just observed and thought about but also carefully manipulated in controlled environments: "the nature of things betrays itself more by means of the operations of art than when at perfect liberty" (Bacon, 1620, p. 341). It also has been the case that along with the development of the scientific approaches to knowledge, from the fourteenth century on, has come the questioning of current dogma in an ever-widening domain of scientific progress. Accordingly, science creates its own growth in what may be a never-ending spiral of questioning, hypothesis building, testing, and discovery.

Because perception cannot be divorced from consciousness, it is appropriate that some of the major philosophic and metascientific issues surrounding the study of perception be discussed, albeit briefly, in order to provide the reader with a broad perspective for the perceptual phenomena covered in later chapters. The view offered of the nature of experience, a type of emergent dualism (Searle, 1992; Chalmers, 1995; Scott, 1995), is meant to allow the reader to place perception in the context of the mind–brain problem and to view the latter in a contemporary philosophic context. In what follows, however, no attempt is made to develop a philosophic tract on epistemology or ontology. Rather, the views expressed simply represent a set of metascientific precepts or at best, heuristics about mind and matter that are consistent with contemporary physical and neuro-science. For example, there is now, at the beginning of the twenty-first century, overwhelming evidence that brain function and consciousness are intimately related. Therefore, this fact is recognized in the discussion of the relation between structure and function, and of conscious states as one of two aspects of reality. The pro-intuitive presumption that conscious states are *real* serves, of course, to sidestep the various philosophic positions that challenge the special nature of consciousness in an otherwise physical universe. However, I believe it is scientifically fruitless to deny the special status of conscious states for, among other implications, to do so would be to foreclose on framing what may be the most significant scientific question of all time; namely, What is the nature of the physical basis for consciousness? In this spirit, in the following sections a few additional issues are raised about the nature of perceptual experience in the hope that the metascience of one era will yield the scientific subject matter of another.

Elements of Consciousness

The Illusion of Publicity

Apart from a historical perspective, the study of visual attributes such as color, size, depth, movement, and so on may have received priority among scientists because of certain phenomenologic characteristics that give them the appearance of being objective and publicly observable, and therefore as being legitimate objects of serious scientific inquiry. Certainly, in comparison with pain qualities and other emotive and aesthetic experiences, visual qualities are perceived to exist at some distance from and independently of the observer. In fact, the externalization of experience itself may be considered a scientific problem (von Bekesy, 1967, pp. 220–228), such that once the conditions of externalization are understood the inner–outer locus of experience could, in principle, be manipulated at will. Considerable progress in this direction occurred in the case of sound localization, where tones may be made to appear either within the head or at some distance in surrounding space (Hartmann, 1999). However, pain, in contrast to visual and auditory experience, may be the paradigm case for a subjective experience because pains always reside on or within the observer and therefore are not experienced as publicly observable. However, because all experience has its seat in the brain, including the quality of being at a distance, none can be said to be more objective than any other. It seems clear why naive realism, the reification of subjective events, is no longer held as a viable doctrine, although the sense of object permanence and stability that the experience of externalization provides is quite real. Therefore, another reason must exist for the preference toward visual problems.

Stimulation and Common Sensory Response

Although it is true of all the qualities of experience that they are private, and therefore that one can only *have* the experience but not observe it, nevertheless it is much easier to communicate about visual sensations than about pain or aesthetics. There is one overriding reason for this to be so. In order to communicate about blueness or many other visual qualities, all one must do is present the stimulation known to produce the experience in question. Even the ancients could do this using pigments, well before any correct formulation of the nature of radiation was available. As long as our nervous systems are not too different (see discussion of structure and function the following), then we can reasonably be assured that exposure of our sensory end organs to common stimulation evokes in each of us a similar though equally private experience. Thus, the scientific requirement of control and reliability of visual experience can be achieved relatively easily by manipulating the sources of stimulation. It seems quite likely, therefore, that the relative ease of controlling visual stimulation has been the major factor that has lent itself to the rapid development of the visual sciences. Let us now, by contrast, consider developing a similar approach to pain.

Ethical issues aside, the control of pain stimulation is quite complicated: many stimuli are internal and are not easily accessible, there is no specialized sensory end organ or common site of application, there is no readily available lexicon to describe the results of stimulation, and it is difficult to quantify the applied stimulation. It is apparent that the difficulties with the development of pain research lie not in the private nature of the pain experienced but in the control and application of the relevant stimulating and inhibiting conditions (Hilgard, 1978; Watkins & Mayer, 1985).

The study of aesthetic experience, likewise, would benefit from appropriate analysis and control of stimulating conditions. Of course, cognition and memory are of critical importance in this domain because they contribute to the stimulating conditions in the brain circuitry involved in the aesthetic experience. It seems reasonable to conclude that conscious experience varies from person to person to the extent to which idiosyncratic cognitive factors contribute to the stimulus package.

Aspects of Reality

Direct and Indirect Aspects

It is perhaps worth noting that with the exception of recursive brain circuitry, the stimulating conditions referred to previously represent the physical properties of our universe that are capable of eliciting a sensory response. These are the collections of atoms, molecules, photons, and all the radiation of the electromagnetic spectrum to which our receptors are responsive and which underlie the objects and qualities of our perceptual environment. These energy distributions constitute the physical aspect of reality that because of the fluid nature of science that proceeds by ruling out competing hypotheses, is always to be regarded as provisional and indirect. We get to know this aspect of reality only in terms of the most contemporary physical science concepts that have survived the rigorous procedures of scientific test and confirmation. Because physical reality is always formulated through the filter of science, it necessarily must be understood as provisional and indirect.

All the various types of energy distributions applied to receptors at the proper energy levels become transduced into a single type of electrochemical energy, which, in turn, is transmitted over neurons to the brain in the form of a train of nerve impulses (Tamar, 1972). One way the brain responds to this stimulation is with the production of conscious experience, the variety of which depends both on the temporal pattern of nerve impulses as well as on the particular spatial locus of stimulation received within the cortex. Conscious states and the various qualities of experience by which they are expressed represent the second aspect of reality, one that arises directly out of brain stimulation rather than through the inferential structure of science. Accordingly, indirect realities represent the physical entities (i.e., energy distributions) that may be said to exist in nature independently of any nervous system. In contrast, the direct realities that arise out of brain stimulation exist solely by virtue of their dependence on brain function. The qualities of sensory experience and other states of consciousness, thus, have no existence apart from a properly structured and stimulated brain from which they emerge. Much like two variables that when applied jointly in an experiment may produce a result that is more than the sum of the effects of each applied separately,consciousness itself may be regarded as an emergent effect of a nonlinear interaction (Scott, 1995). Also worthy of consideration is Sperry's (1985) suggestion that "the events of inner experience, as emerging properties of brain processes, become themselves explanatory causal constructs in their own right"(p. 379). Such a view actually finds expression in theoretical claims about perceptions causing perceptions such as increased perceived distance causes increased perceived size and so on. See Chapter 6 and also Kaufman (1974, p. 23) for a brief discussion of this issue.

Virtual Reality and Nonveridical Experience

Not all conscious states are in correspondence with certain energy distributions that constitute the physical objects of our environment. Dreams, hallucinations, and experience resulting from direct electrical brain stimulation (Penfield & Perot, 1963) represent conscious states produced without the presence of the physical energy distributions that normally would provide brain stimulation via peripheral sensory channels. When perceptual phenomena no longer justify a claim about the existence of some physical entity, then our perceptual experience cannot be said to be veridical or "truthful." This state of affairs occurs regularly in the course of illusions, the most common of which are due to the reflection of light from mirrors and movie screens. To be sure, although visual experience entailed by viewing the light reflected from a mirror or screen would of course be real, any claim for the existence of a physical object at the place signaled by the light rays would be in error. In general, experience may be nonveridical whenever we use the senses as though they were sensors of one or another energy distribution. Thus virtual reality devices warrant their name because no claim for the presence of the physical entities portrayed would be justified, although it would be proper to claim the existence of radiation in the visible range of wavelengths. However, drug-induced visual hallucinations would not even justify that claim and therefore may be considered totally nonveridical.

Brain as Mind Machine

The Relation of Structure to Function

There is one truly central problem that confronts all who have ever pondered the nature of perception, and that concerns the relation of the qualities of experience to the cortical structures that support them. Although this is, of course, an ancient question, there is a peculiarly modern ethical side to the mind–body issue that derives from an analysis of the relation between structure and function.

The brain is a remarkably complicated structure of billions of interconnecting neurons, some portion of which is associated with consciousness. In fact, the brain may be regarded as a mind machine, a device whose functions include the production of conscious states. Viewed in this fashion, like any other functional mechanism, brains represent mechanisms whose structures are intimately related to their respective functions. This is not to say that the same result, consciousness, may not occur from the exercise of different brain-building principles and different mechanisms or structures. Rather, it is to assert that if one builds two devices identically, except for trivial differences, then when activated, the functions or output of those devices must also be identical. When applied to brains, this has been called the Principle of Organizational Invariance, meaning that "any two systems with the same fine-grained *functional organization* will have qualitatively identical experiences" (Chalmers, 1995, p. 214). Because functional organizations may in principle be duplicated in computer chip architecture and biological systems, the interesting implication may be drawn that, according to this view, "the qualitative nature of experience is not dependent on any particular physical embodiment" (G. Glaser, personal communication, August, 2000).

Just what there is about the architecture and dynamics of brain processes, such as perhaps highly correlated streams of neuronal activity (Tononi & Edelman, 1998), that supports consciousness and accounts for the differences in sensory modalities, such as vision and hearing, is of course presently unknown. Nevertheless, neuroscientists are moving rapidly to develop the capability of simulating extant neural networks. For example, certain laboratories have grown neural networks on transistors with which the neurons have subsequently interacted (Service, 1999). Given the intimate relationship between structure and function, the ethical problem of having inadvertently stimulated consciousness in a simulated brain must then also be seriously considered.

A Role for Motor Systems in the Study of Perception

In the present work, only a restricted range of conscious experience is treated. Namely, those phenomena traditionally studied under the category of space perception. This includes the qualities of motion, depth, size, distance, slant, and spatial location. In the quest for scientific explanation of these phenomena, it has been useful to specify their antecedent conditions by examining the nature of stimulation, either in the sensory end organs (e.g., the retina) or in the brain itself. For example, motion perception may be determined by a certain succession of images across the retina, as occurs when viewing movies, or by a truly moving image. In either case, typical explanation is based on analysis of the properties of the pattern of stimulation input to the nervous system and associated internal processing channels (Livingstone & Hubel, 1987). In essence, this approach seems to imply that an explanation of sensory experience requires the explication of information input to the sensory channels as well as analysis of the structure of the channels themselves. Although it seems to be an intuitively proper heuristic to conduct perception research in this fashion, the approach, although fruitful, is necessarily incomplete. One reason for this is simply that motor systems, especially oculomotor systems, contribute certain qualities of experience, and no amount of analysis of sensory channels or sensory information can uncover the role played by motor systems.

From a historical perspective, the impetus for the separate study of sensory and motor systems stems, in the modern period, from the work of Charles Bell (1811) and Francois Magendie (1822). The Bell–Magendie Law, embodying their experimental results, ascribes a sensory function to the posterior roots of the spinal cord and a motor function to the anterior roots. This clear separation of sensory and motor function currently is recognized as efference, or nervous outflow from the brain; and afference, or inflow from sense receptors. Such a dichotomous representation, however, could not survive for long for two reasons. First, by the mid-1800s, various detectors [e.g., muscle spindles and Pacinian corpuscles, which signal muscle stretch and changes in cutaneous and deep pressure, respectively (Tamar, 1972)] had been found in muscle tissue and along cutaneous nerves and internal organs (Boring, 1942). Actually, it would appear that purely motor systems without a sensory apparatus may not exist as such. Second was the well-known concept of "innervation feelings" (Scheerer, 1987), culminating in Helmholtz's (1910/1962, Vol. 3, p. 245) proposal that efference, or the effort of will, may be registered in consciousness so that even without sensory feedback from peripheral detectors, awareness of limb, or eye position, would be possible. Thus, even at the origins of modern physiology and psychology, motor systems were thought to be implicated in space perception, and, conversely, Bell (1826) noted the importance of the "nervous circle," or what we would now call "sensory feedback," for precision of movement.

Presently, although there is a growing interest in the interactions between sensory and motor systems and their impact on perception (e.g., Bouwhuis et al., 1987), nevertheless, the specific role of oculomotor systems in perception is not widely known. In contemporary times, the tendency to treat sensory but not motor systems as sources of spatial information can be found even in developments in the robot-design community, where, for example, sophisticated electronic circuitry and machine-vision algorithms are used to drive robot motor systems (Indiveri & Douglas, 2000). Such modern endeavors are strangely reminiscent of seventeenth- and eighteenth-century approaches that, after Descartes' earlier mechanistic physiology, modeled behavior as a reflexive response to sensory processing (Peters, 1965), but ignored both the qualitative and metric contributions of the motor system itself to visual experience.

Egocentrically Speaking

Perhaps the most significant illustration of how an oculomotor system may play a role in perception may be drawn from the experience of egocentric direction. Any visually represented object is perceived in a space around an observer at some particular location in relation to the self, or ego. This, of course, is a remarkably functional fact, for knowing the position of an object enables one to act with respect to that object by, for example, catching or grabbing it, moving toward or away from it, or scanning its features. However, what conditions enable the observer to experience egocentric orientation to begin with?

If, like the owl, eyeball mobility in the head was restricted to only about one degree of arc (Steinbach & Money, 1973), then when an image was formed on the fovea, the object would invariably be located in front of the observer's head. So, if the position of the head on the trunk were known, then hands and feet (or wings) could be directed to move accordingly. However, because our eyes are quite mobile in the head, a foveally represented image, or an image represented anywhere else on the retina, may have come from an object at any one of a large number of places in space. Under these circumstances, there would no longer be a one-to-one relationship between the position of an image on the retina and the position of the head in relation to the object. Because a foveal image could arise from the light of an object above, below, left, or right of the observer, all depending on eye position, one is compelled to conclude that eye-position information must be present to disambiguate what would otherwise be an extraordinarily ambiguous location-finding task. Thus, oculomotor systems may be said to contribute a sense of "thereness" to visually apprehended objects.

Single points seen in otherwise total darkness are readily localized (Matin, 1986). Therefore, the quality of experience represented by "there," or egocentric spatial location, as opposed to "what" (Ingle, Schneider, Trevarthen & Held; 1967, Held; 1968, Leibowitz & Post, 1982), is not necessarily based on the extraction of information in the scene from the optic array, as might be said of the perception of boundaries or contours. Rather, like the experience of color, it simply is attributed to the object based on extraretinal eye-position information (Matin, 1986). Accordingly, the role of oculomotor systems in imputing certain qualities of experience to objects is discussed in Chapter 4 as an *attributional* approach to perception.

The principal message of this volume is that oculomotor systems play a significant role in accounting for certain qualities of visual experience. No attempt is made, however, to address the classic issue of how the various oculomotor systems come to signal egocentric location or other visual attributes, whether through learning and development (Held & Hein, 1963; Hein & Diamond, 1983) or via evolutionary mechanisms (Rose, 1999). Once the importance of oculomotor systems has been stipulated, the need to study eye movement systems is apparent, and these are covered in Chapter 3. Furthermore, because eyes are mechano-optic systems, the need to introduce basic concepts in physical and physiological optics also follows directly. These matters are addressed in Chapter 2, whereas the Appendix introduces some common clinical problems that occur when the physiologic systems break down. Chapters 4 and 5 represent the critical mass of this work, with the empirical substrate for the main thesis in Chapter 4 and, a discussion of selected theoretical issues is left for Chapter 5. A succinct summary and a set of major unresolved problems associated with the present approach is contained in Chapter 6.

2

Some Basic Concepts of Physiological Optics

Introduction

The highly distilled knowledge represented in this chapter took centuries for the early Greek and later Arabic scholars to develop. Enormous efforts were made especially during the middle ages to transmit this knowledge from the Ancients by providing translations from Greek into Arabic and Latin, and later into the other languages of Western Europe (Lindberg, 1978a).

The issues that had to be argued about, thought through, and developed for about two millennia were extraordinarily basic, such as the rectilinear propagation of light; the structure and position in the eye of the sentient surface leading to perception; the nature of refraction, especially within the eye; vision due to extramission of radiation from the eye vs. intromission of light from objects into the eye; that light emanates in all directions from each point on an object; and that the relationships between points on an object had to be maintained in the image within the eye. It was not until 1583 that Felix Platter, a medical peer of Johannes Kepler, correctly placed the visual sensory mechanism in the retina and not at the lens (Lindberg, 1976, 191–208). Armed with this insight, in 1604 Kepler provided the correct refractive path of light through the cornea, pupil, lens, and all refracting media; offered the correct theory of the inverted, reversed retinal image; and demonstrated how all light rays emanating from a point in the visual field are brought to a focus at one point on the retina (Lindberg, 1976, 1978b).

In the context of oculomotor systems, it is recognized that visual stimulation plays a large, but not unique, role in the control of eye movements. As a step toward understanding the role of vision in oculomotor control, it is necessary