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HELMHOLTZ'S METHODOLOGY OF SENSORY SCIENCE, THE *ZEICHENTHEORIE,* AND PHYSICAL MODELS OF HEARING MECHANISMS

1. INTRODUCTION

Hermann von Helmholtz (1821–1894) was one of the most productive scientists to contribute to the understanding of perception. His treatises on vision and hearing continue to exert a notable influence on the sciences of perception.[1] For Helmholtz and his contemporaries, the science of perception was an independent enterprise, distinct from the philosophy of perception, just as the two are distinct today. However the two areas of inquiry were more closely in contact than they are today. In fact, Helmholtz developed a general framework for conceiving of perception that went beyond a purely naturalistic explanation of how humans perceive. The framework outlined a set of normative conditions for perceptual knowledge in general. His general theory has been called the empiricist theory of perception, and it includes as proper parts the sign-theory of perception (or *Zeichentheorie*) and the theory of unconscious inference. In this paper I explore an interpretation of the *Zeichentheorie* and argue that Helmholtz maintains a strong residue of a causal realist theory of perception throughout his life. The argument will include the discussion of a case study from Helmholtz's research on hearing, specifically, his influential resonance theory of hearing.

Several recent discussions of Helmholtz's philosophy have highlighted the unique quality of his sign-theory of perception, or *Zeichentheorie.*[2] There has been some debate regarding the precise status of perceptual reference to physical objects and properties in the course of the evolution of Helmholtz's theory of perception. It is generally agreed that the *Zeichentheorie* postulates a causal connection between the perceiver and the perceived, and that early in his career Helmholtz grants this causal connection strong epistemic status. The causal connection between world and agent, particularly the inference of a causal connection by the perceiver, allows for the perceiver to cross the veil of perception. However, later in his career Helmholtz qualifies the claim regarding access to the external world via the principle of causality. Some have argued that the qualifications regarding perceptual access to the external world amount to a rejection of Helmholtz's early causal realism. The debate on which I will focus concerns the meaning and extent of this qualification. Some suggest that he ends up defending

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some form of pragmatism, while others suggest that he ends up defending a form of idealism.[3]

The case study from his research on hearing, aims to show that despite qualifications that moderate his causal realism, he does not give it up. By causal realism I just mean a theory of perception whereby the act of perception consists in a causal relation between mind-independent objects or events and the perceiver. Perceptual knowledge consists in some specific reference to the properties of physical objects that play a causal role in the perceptual event. For Helmholtz to give up on reference to causal interactions instantiating purely physical properties, not themselves directly sensible, would be giving up on his basic research strategy in two ways. It would have required a major modification in his understanding of the role of one-to-one coordination in the account of perceptual knowledge offered by the *Zeichentheorie*. Abandoning this notion of causality further would have required a major revision in his reductionistic explanatory strategy in sensory science. In both the philosophical sphere and the scientific, he continued throughout his career to attribute an important causal role in perceptual processes to purely physical properties.

Michael Friedman has presented a sophisticated argument that Helmholtz abandons (say post 1866–70) a principle of causality that would transport a perceiver, at least figuratively, across the veil of perception. Friedman overly emphasizes Helmholtz's caution regarding how causal inferences bridge the subject/object gap and thus misinterprets aspects of the *Zeichentheorie* that focus upon the psychogenesis of perceptual abilities and the nature of perceptual objects. Friedman recognizes an important distinction in causality but concludes that Helmholtz abandons the aspect of causal inference that links the agent with the external world.[4] From the 1850s onward, Helmholtz's empiricist theory of perception holds perceptual objects to be mental representations composed of complex associations of subjective sensations. Physical objects are inferred to be the causes of sensations, and perceptions are interpretations of sensations through unconscious inferences that implicitly appeal to law-like correlations joining sensations with acts of willful intervention in the world. But the inferred physical objects have their own physical properties that are correlated with but distinct from sensational properties. From the early 1850s onwards, Helmholtz insists that there is no meaningful resemblance between physical properties such as light frequency and sensational properties such as colors. The realms are correlated by causal inferences proceeding from sensational properties to inferred physical causes. This is what happens in normal perception when one experiences a set of color sensations as a single physical object, localized somewhere in a three-dimensional visual field. In a more advanced stage of inquiry it becomes possible (through physical research) to determine and test the physical properties of such inferred objects and the laws that unite physical interactions as such. Then one can postulate laws connecting the physical properties with sensational properties and perceptual objects. This process assumes a second type of causal relationship among sensations and perceptions.[5]

As part of this general explanatory strategy, Helmholtz applied his considerable skills as a mathematical physicist to develop sophisticated models of hearing mechanisms. His models have exerted a considerable influence on the subsequent history of physiological acoustics.[6] The models invoke unobservable functional properties, justified by their heuristic and explanatory power. However, he argues at length that the models' success in accounting for observed data warrants the conclusion that the models correctly represent the function of the inner ear. This says much about the conditions for confirming scientific hypotheses revealing a commitment to explanatory reduction of sensory properties to their underlying causal, but unobservable physical properties. Despite the importance of Helmholtz's well-known qualifications concerning causal inferences as the subject's connection to the physical *per se*, he persistently grants such inferences considerable epistemic weight in his hearing theory in particular, and in the *Zeichentheorie* in general. His claims about pragmatism and idealism notwithstanding, he remained a moderate realist. Though true both of his views on the nature of scientific knowledge as well as perceptual knowledge, I will focus mostly on the manner in which he remains a realist in his philosophy of perception.

Helmholtz's realism rests upon his faith in the truth of physical laws. Well-tested law-like connections among sensations that yield perceptual objects and general features of our perceptual world are not an infallible source of knowledge. Since perception is pragmatic and goal-oriented it functions not as a mirror for the world but as a feature detector for those properties that are deemed essential for the interest of the agent. Perceivers are constantly exposed to a blitz of information. Because of the unconscious and relatively unsystematic manner in which it is represented and tested, he argued that perceptual experience is considerably more fallible than well-tested physical hypotheses. Further, as Helmholtz notes in the 1866 installment of the *Handbuch der physiologischen Optik* (hereafter, *Handbuch*), the laws of physics are more certain than the claim that all men are mortal. The reason is that the causal story is richer in the former case, largely because it is subject to systematic analysis and testing. Thus determining the genuine status of perception as knowledge requires linking the structure and content of subjective perceptual experience to the underlying physical and physiological systems that support perception. The case study in this paper shows how Helmholtz attempts to do this with the basilar membrane and its role in pitch perception.

2. THE NATURE OF THE *ZEICHENTHEORIE*

In his 1997 paper, Michael Friedman presents an exceptionally original and interesting account of Helmholtz's *Zeichentheorie* and its relation to Moritz Schlick's epistemology in the *Allgemeine Erkenntnislehre*. I will discuss and contest his claim that Helmholtz's mature position represents a rejection of

causal realism. As noted, the *Zeichentheorie* embraces both the psychogenesis of subjective perceptual experience as well as the attempts to explain this via the physics and physiology of the unobserved causes of sensational content. Basic perceptual objects are constructed, in Helmholtz's view, through the cognitive association of sensations into law-like connections. But sensations are, by hypothesis, assumed to have a causal origin in the physical world, independent of the world as perceived. That is, Helmholtz seems to assume, both in his presentations of the *Zeichentheorie* in lectures and in his development of it in practice, that there are actual physical objects in the world which carry properties that are not directly sensible.

For example, think of the property of 'mass' that a block of iron bears. As a perceptual object, the block of iron as an object is a complicated collection of colors, textures, tastes, smells, and sounds that are associated with it. Identifying such properties with the object "iron block" is the sort of association of sensations that fits a law-like pattern and thus constitutes the iron block as perceptual object. But Helmholtz held that we know more about the iron block. We can assign it a mass, describe its behavior in free-fall, its chemical properties that cause it to have a specific color, or its tendency to vibrate when struck. These propositions require that there be a relation between the so-called purely physical properties and the perceived sensible effects.

The *Zeichentheorie* was outlined in a series of addresses and publications. These "programmatic" texts were given or published throughout his career, and range from his *Habilitationsvortrag* ("Ueber die Natur der menschlichen Sinnesempfindungen"), given in Königsberg in 1852, to his famous "Die Thatsachen in der Wahrnehmung" delivered in Berlin during 1878.[7] His *Zeichentheorie* has been equated with his general theory of perception.[8] While this may be acceptable in rough terms, I would like to limit the *Zeichentheorie* to the following more limited claims:

a.) Sensations are mere *signs* of their objects, resembling the latter in no meaningful way.

b.) Interpretation of sensory signs requires coordinating them into systems of law-like relations.

c.) Law-like relations consist of *intra*-level relations (perception to perception, sensation to sensation, physical property to physical property) as well as *inter*-level relations (physical properties to sensory signs; sensory signs to perceptual objects, etc.)

A simple way to characterize the status of knowledge, perceptual and scientific, within this scheme is that knowledge refers to exceptionless law-like regularities. Correspondence can mean little more than functional dependence. I do not intend to imply by this that any level must be constructed out of any other. In discussions of the epistemology of geometry Helmholtz emphasizes the primacy of the subjective perceptual properties of spatial intuition and the consequences of his epistemology of perception for understanding the nature of geometrical axioms.

His discussion of the causal law in later writings emphasizes the tentative nature of its link between subjective sensory properties and physical properties. Thus he became quite cautious of making any claim to definitive truth regarding unobservable properties in physical theories and models. In 1878 he even calls the existence of an external world, a fruitful hypothesis, concluding that without certainty of its existence, we must simply trust and act. However, at the same time his approach to sensory science was unabashedly physicalistic, and he built his entire methodology on telling the detailed history of a physical signal, following it through physiological processing and terminating in psychic perceptual experience. The interpretation of his *Zeichentheorie* as a theory of perception, as an epistemology, as a methodology of sensory science ought to reflect his appeal to each distinct level of event. Each level bears unique properties, and each has its own status as a node within the total scheme of law-like relations.

The argument for the *Zeichentheorie* relies upon the fact that there are numerous possible causal arrows between various levels. There can be different causes in the object realm (a live orchestra, or a high-fidelity reproduction). A tuning-fork, an electronic synthesizer, or an electrical stimulus of the auditory nerve may each cause the sensation of a simple tone. In short, the same kinds of sensations can be caused by non-identical physical or physiological sources. On the other hand, the same type of physical energies, when processed through different sense modalities cause different subjective experiences. A pressure wave in the air may be perceived as a tone via the hearing system, or as a tactile vibration via the tactile sensory system. Single sensations appear to have multiple relations with objective causes. Thus, starting from sensations and inferring their unobserved causes is a tenuous endeavor.

It is possible, he argues, to coordinate objective causes with subjective experiences. Given a pressure wave of specified frequency acting upon a normal auditory system, there will always be a tonal sensation of a certain pitch. Yet given a tone of a certain pitch, it is not possible unequivocally to determine a pressure wave of a certain frequency. Such tones could be the product of electrical stimulation of a certain auditory nerve, or even of spontaneous brain activity. Right there is a clue that he would never attempt to locate knowledge of objects in laws restricted to coordinations among sensations. His very own *Zeichentheorie* seems to forbid it. Thus, he must always help himself to physical (and physiological) properties to guarantee one-to-one correlations.

As I indicated, the property mismatches among levels suggests another challenge. A major premise supporting the *Zeichentheorie* is that physical and physiological causes of sensations bear properties entirely incommensurable with subjective sensational and perceptual properties. Tuning forks have mass, resonance frequencies, and dispositions to reflect certain wavelengths of light. Air molecules bear similar physical properties, as do the mechanical parts of the auditory system. The auditory nerves have physical properties as well, but they also bear electrochemical properties too. The relevant physical properties are

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