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Demonstration by Simulation: the Central Place of Experiment in Helmholtz's Theory of Perception.

1. Introduction. Psychologists Jean−Claude Risset and David L. Wessel (1999) have recently describe techniques they have developed to study tonal timbre perception. Timbre is the quality of a sound that picks it out as unique, or that which picks out a violin playing F, as opposed to a piano playing the same note. To understand the causes of timbre they say it is important to "extract significant features from a complex physical structure." (118) Then one can correlate physical properties such as frequency, amplitude, amplitude on−set rate with the subjective experience of timbre. In pursuit of such correlations they attempt to "control through synthesis the aural relevance of the features extracted in the analysis—to perform analysis by synthesis." (1999, 118) They conclude that this has only recently become possible "thanks to the precision and flexibility of the digital computer." (118) Ironically one of their sources, Hermann von Helmholtz's *On the Sensations of Tone* (1863/77 − they cite it) did just exactly this by synthesizing human vowel tones with his series of electromagnetically−driven tuning forks. Helmholtz's effort was not simply an esoteric bit of experimental gimmickry—it was intimately tied to a much more ambitious program of sensory science and a distinctive philosophy of perception.

Helmholtz (1821−1894) developed a comprehensive theory of perception, which operated at philosophical and scientific levels. His views on the nature of perception feature prominently in his vision and hearing research. The theoretical roots of his account of perception have been traced to Helmholtz's philosophical and scientific predecessors. Possibly the most important of these are Immanuel Kant, Johann Gottlieb Fichte, and Johannes Müller. In part this genealogy is correct. But Helmholtz's ideas have important roots in the laboratory as well. Undoubtedly he owes much to philosophical predecessors such as Kant, Fichte, Locke and Mill. However, the search for his debt to particular philosophical currents sometimes obscures the central role of his (and predecessors') scientific and experimental work in the origin, conceptual content, and practical significance of his theory of perception. This I wish to highlight. His philosophy and science of perception must be understood in the context of his practice, even if practice alone fails to exhaust the matter.

More specifically I argue that experiment (theory and practice) is the glue that holds his theory of perception together. It plays three crucial functions. One, the arguments for his theory of perception appeal to and arise out of empirical and experimental research. This is not a novel opinion.[1] However I think its full significance has yet to be appreciated. Two, the idea of experiment fulfills a critical gap both in his philosophical and scientific theories of perception. In short, the senses alone fail to reach the nature of objective actuality. However he was no sceptic. The senses simply need (lots of) help from experimentation coupled with the discovery of law−like relationships to achieve any knowledge of objects and events. Thus experiment plays a central conceptual role. It functions not merely as a scientific technique, but also as a general epistemological strategy. Three, Helmholtz's experimental practice elaborates his theory of perception, applying its central lessons to his studies of hearing and vision. These works provide a crucial set of examples indispensable for understanding his theory, particularly what he meant by this generalized concept of experiment. On the other hand, the consequences of the theory help to explain the shape that his experimental style took on.

To clarify the third function, I focus on a series of experiments from Helmholtz's physiological acoustics in which he synthesized human vowel sounds to support his proposed explanation for human vowel production and perception. Because hearing has important limitations, new laboratory instruments were required to produce and analyze tones. By producing tones he could specify the physical properties of their component parts. With his resonators he was able to amplify these signals to allow the perception of components never before accessible. This may not seem too surprising—that is what one does in an experimental science of the senses. However the research strategy of coordinating, in tight functional relations, physical signals, physiological codes (signs), and psychological percepts (representations) was emerging largely through the comprehensive synthetic projects represented by Helmholtz's *On the Sensations of Tone* (1863) and *Handbook of Physiological Optics* (1867/1909−11). So it was not obvious when he took up these projects that a science of the senses must proceed this way. Nor was Helmholtz's particular interpretation of the meaning of this method unanimously accepted But it was extremely influential and his theory of perception was importantly connected to his experimental method. In short I hope to show that Helmholtz's experimental inquiries play a (if not THE) central role in developing his theory of perception, in providing a coherent picture for how perception might achieve an objective grasp of the properties of nature, and in elaborating an enduring methodological framework.

2. Empirical Roots of the *Zeichentheorie* and Unconscious Inferences

Helmholtz's theory of perception combines two independent notions or sub−theories. The first is known

1 Recent work by Hatfield 1990, 1993, Friedman 1998, Schiemann 1997 make this point very plain. It is in fact a point made by many earlier scholars.

as his *Zeichentheorie* or sign−theory. Stated briefly, sensations are not images of external objects, but signs we learn to correlate with their causes. The theory of unconscious inference asserts that cognitive processes necessary for unified perceptual objects, mirror the structure of conscious logical inference. However the processes take place without attentive awareness. I will describe both notions further below. His theory of perception comprises both philosophical and scientific domains. It distinguishes perceptual experience from mere sensation. The theory attempts to explain what, if anything, perceptual knowledge is. And it distinguishes perceptual properties such as color, smell, feel, and pitch from those that are physical, e.g. wavelength of light, pressure, frequency, and so on. En route to this synthetic view he divided the study of perceptual systems into three distinct regions: physical signals, physiological signs, and psychological percepts.

I wish to trace the barest outlines of his argument for the sign−theory as it appears in two of his early lectures (Helmholtz 1852 and 1855). The lectures shed light on the relative importance of the empirical and philosophical background to his theory. In both lectures Helmholtz's argument for the sign theory appeals extensively to empirical work in the physics and physiology of vision, and specifically to the doctrine of specific sense energies owing to Johannes Müller. In his 1855 lecture, "Ueber das Sehen des Menschen" Helmholtz also explicitly discusses Kant and Fichte and the tone is conciliatory. He suggests that the two great philosophers saw science and philosophy as fellow travelers. In the case of Fichte he simply says that "his account of the sense perceptions is in the most exact agreement with the conclusions which later the facts of experience have brought forth." (1855, 89) This hardly signifies an essential debt, and Helmholtz's tone suggests that, despite great respect for Kant and Fichte, the case for his account was not made until the scientific work had been done. Much of this work was done by Johannes Mueller, but Helmholtz himself had contributed importantly as well, even at this early stage of his professional career.[2]

The first formulation of the sign−theory occurs in Helmholtz's *Habilitation* lecture "Ueber die Natur der menschlichen Sinnesempfindungen." (1852) given in Königsberg. He briefly but systematically explores how sensations might correspond to the sensed objects. It is notable that his argument proceeds through a discussion of color vision.. This first formulation was not as complete as later versions would be (1867 or 1878), but he essentially maintained its core with little change, outside of the important issue regarding the nature of causality in the theory. [3] The basic argument proceeds as follows. A single type of stimulus can produce various kinds of

2 The occasion of the *Habilitation* lecture in the following discussion was to comment upon his *Habilitationsschrift* recently completed on the theory of color mixtures.

3 For different views on the evolution of the sign−theory see Hatfield 1990 and Schiemann 1997.

sensation, depending upon which sensory system processes it (a one−to−many relation). Further, diverse types of stimuli can produce the same type of sensation in a single sensory system (a many−to−one relation). This diversity suggests that there is no resemblance between sensations and the objects that cause them.

The first, or one−to−many argument re−states Müller's doctrine of specific sense energies. Identical physical stimuli are processed into completely different forms by each sensory modality.[4] Thus the same radiant energy that is processed as visible light by the vision system, is processed into warmth by the tactile system. What is felt as changes of pressure on the skin, is processed as sound by the auditory system. The sensations delivered by the senses to the cognitive faculties are at best partial samples of their physical causes (objects, events) but are better thought of particular types of reactions that depend upon the reacting sensory system for their particular quality. Given this quality, they function as signs that we correlate with their respective causes.

The more effective argument appeals to the many−to−one relation. In other works he discusses various types of stimulation processes that yield qualitatively indistinguishable sensations. So a flash of light can be seen if there is a flash of light, if there's a blow to the head, or if an electrode stimulates the optic nerve. By hypothesis anyway, the three objective processes are subjectively identical. He goes further, noting that physicists were developing precise accounts of the nature of light as a wave−phenomenon. But humans do not see light as a vibrating wave phenomenon. Our perception depends heavily upon the unique properties of human sensory physiology. So there are ranges of light energy that differ from visible light slightly in frequency, but yet are not visible. He concluded that light sensations correspond neither to the range nor the quality of the physical phenomena of light. (1852, 606) In short, there is light that causes in us no light sensations, and light sensations not caused by light.(1852, 605)

In his 1852 lecture he mixes the two kinds of argument to show that colors should not be thought of as properties of objects (1852, 607). Bodies appear colored by reflecting certain wavelengths of incident light. The selection depends upon the unique properties of the body. However under certain light, a set of three objects may reflect three different colors, say red, orange and red−orange. But under brighter light all three appear to be the same color. Two different bodies under day−light may appear to be the same color, while under lamp−light different colors. So it appears that bodies of very different natures can appear to be the same color, while those of like natures can appear very differently colored. This leads him to conclude that "We could maybe most forcefully characterize the relation when we say: Light and Color sensations are only symbols for relations of actuality; they

4 This is essentially the point of the doctrine of specific sense energies developed by Johannes Müller, under whom Helmholtz studied in Berlin.

have with the latter just as little and just as much resemblance or connection as the name of the person or the series of letters for a name with the self−same person." (1852, 608).

The wider lesson is that sensations alone can provide no objective representation of actual objects. We can't know the nature of objects directly, but can know them indirectly by discovering the laws guiding the interaction of objects and our sensory apparatus. Science plays a starring role in telling this objective story.

The 1855 lecture "Ueber das Sehen des Menschen" addresses the issues of the sign−theory with very similar appeals to empirical physiology, but it carries the argument further into the theory of unconscious inference. He moves in this direction arguing that having light sensations is not yet seeing; rather, "seeing consists first in the understanding of light sensations." (1855, 99) Not all light sensations are the result of light energy entering the eye. In cases where electric current enters the eye, we "see" a flash of light, and in such a case the sensation stimulates not a veridical perception but an illusion. Illusions occur simply because the mind has constructed rules based upon millions of experiences in which sensations are interpreted or synthesized in characteristic ways. An illusion occurs when unusual circumstances produce sensations that fit into a "normal" pattern that differs objectively from the present circumstances. Rules emerge through the cognitive capacity to judge, infer and reflect unconsciously. Helmholtz illustrates this capacity of the mind by appeal to experiments on the human blind−spot, experiments with Wheatstone's stereoscope on binocular vision, as well as problems in spatial perception. The result is a fully conceptualized notion of perception, where the conceptualization mostly occurs unconsciously and its primary aim is towards successful action (1855, 107).

Both the notion of the sign−theory and unconscious inference have philosophical roots and implications. But the rhetoric he employs places the focus on their empirical foundation, much of which is experimental. The next role for experiment follows from the cleft he outlines between the senses and nature. He conceives of the sensory systems and resulting perceptions as highly limited and fallible in their representation of nature. The properties of sensations are non−identical to physical properties, and because we process sensations unconsciously with the goal of successful action, much of the information in sensations gets systematically ignored. The question then arises, how to overcome these limitations.

The concept of law holds together any claim to knowledge because the senses cannot do the job alone, nor can pure concepts. He articulates forcefully this link between the sign−theory and his notion of law in his most philosophical lecture, "The Facts in Perception,"

> Insofar as the quality of our sensation gives us information about the peculiarity of the external influence stimulating it, it can pass for a sign − but not for an image. For one requires from an image some sort of

> similarity with the object imaged: from a statue, similarity of form; from a drawing, equality of perspectival projection in the visual field; and from a painting, similarity of colors. A sign, however, need not have any type of similarity with what it is a sign for. The relations between the two are so restricted that the same object, taking effect under equal circumstances, produces the same sign, and hence unequal signs always correspond to unequal effects. (1878, 347)

And soon thereafter he argues that though this residue of similarity may seem limited, it is not. An imaging (*Abbildung*) is possible of the law−like processes occurring in the world.

> Each natural law says that, given preconditions which are alike in certain respects, consequences which are alike in certain other respects will always follow. Since likeness in our world of sensation is shown by like signs, then there will also correspond to the natural−law consequence of like effects upon like causes a regular consequence in the field of our sensations." (1878, 348).

Even though sensations are signs whose particular character depend completely upon our organization they should not be dismissed as mere appearances. They are signs of something definite and knowable, whether an enduring thing or an event . Most importantly the laws of these events can be discovered. They are projectible in the future because of the law of causality. His appeal to the law of causality is akin to the Kantian notion that we must pre−suppose causality in order to have any objective experience.[5] The synthesis, coordination and exceptionlessness of the notion of law allows for the products of the senses to lead to knowledge. But to reach the regularities of normal perception and the precise laws of physics, a merely observational use of perception would fall short; there must be experimental activity.

3. Experimentation as Helps for the Senses

Experimentation, conceived broadly as an active process of deliberately varying conditions, fulfills a central task in both the scientific and philosophical parts of the theory of perception. Mere observation can not provide the crucial information needed to isolate the essentially co−occurring properties from those that are inessential. But experiments can. "By comparatively few carefully executed experiments we are enabled to establish the causal conditions of an event with more certainty than can be done by a million observations where we have not been able to vary the conditions as we please."(1867, 30) This applies to normal perceptual learning as well as experimental laboratories. (1867, 31) Experimentation must be directed through the active involvement of the will in deliberately altering conditions and observing the results.[6] He illustrates this idea in a late essay (1894) describing how young children first learn the meaning of their visual representations by playing with toys.

> Notice how they handle them, consider them by the hour from all sides, turn them around, put them into their mouths, and so on, and finally throw them down or try to break them. This is repeated every day. There can be no doubt that this is the school in which the natural relations among the objects around us are learned, along with the

5 Helmholtz 1855 discusses this in the case of assuming that some outer object must be the cause of our sensations as well as the assumption that any effect must have a cause, which would link a train of causal effects. For more complete discussion see Friedman 1998, Hatfield 1990, Heidelberger 1993, and Schiemann 1997.

6 The notion of active intervention is discussed at length by Hatfield 1990 and by Heidelberger 1993.

understanding of perspective images and the use of the hands. (1894, 505)

The concept of experiment takes assumes then a central place in his general account of perceptual learning as well as his epistemology of perceptual acts.

Helmholtz's view depends upon a distinction between deliberate and conscious. Perceptual learning is experimental because it proceeds according to the same general form of deliberate altering of conditions, testing different arrangements, and applying the knowledge gained in new circumstances. Further both activities lead to knowledge in precisely the same way—by picking out the law−like in experience. Scientific experimentation simply employs the same idea much more exactly and thus can fit its results into a mathematical framework.

Perceptual acts, guided by experimentally active experience, can isolate the essential co−occurrences of sensory information that are synthesized by the mind into unified objects of experience. Higher level abstractions and identifications of more general law−like relations allow for the identification of more purely physical properties and their correlation with sensible properties. Examples include correlation between frequencies of light with color sensations, or between frequency of air compressions with tonal pitch. Even the conviction one experiences in the perception of single objects, like the table in front of me, always appeal to law−like relations (often merely implicit and unconscious) among sensations, objects, and events. Thus as a theory of perceptual and scientific knowledge, Helmholtz's view rests much of the epistemic work on the shoulders of law. However, the notion of active experimentation is the necessary step to any notion of the law−like, both in the moment of discovery and in that of critical testing. Perhaps this central role will appear more concrete when viewed in action.

4. Experimentation in Practice: Analysis and Synthesis of Human Vowel Tones

Helmholtz's *Sensations of Tone* continues to exert a measurable influence on those who study hearing, acoustics, and particularly the psychology of music.[7] His aim was to explain musical harmony, by tracing the sources of harmonic intervals in the physiology and psychology of tone perception. On the way, he visited many specific topics in acoustics and audiology, such as his beat theory of consonance, and his resonance theory of hearing. In addition to experimental and instrumental innovation, he considerably developed issues in the anatomy, physiology and the physics of acoustics. These skills allowed him to pursue research at the leading edge of the three crucial aspects of hearing perception.

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7 A glance at the recently published collection *Psychology of Music* (Deutsch 1999) indicates the enduring importance of Helmholtz's work. Of the six essays that I examined, each one referred to the *Sensations of Tone* in the bibliography, and at least three explicitly discussed Helmholtz's work.

The larger program found its roots in a highly experimental approach in which two themes are characteristic: **analysis** and **synthesis**. Because of the inherent limitations of sense perception, he developed innovative ways to observe specific tones, whether from the human voice, or musical instruments. This is what I mean by analysis. A crucial example of such “helps” are Helmholtz’s resonators. This will be discussed in detail below. The idea of synthesis arises largely from his idea of exact laws. The most exact laws are found in mathematical physics, and it is with the eye of the mathematical physicist that he approached sensory physiological issues. He developed experimental apparatus’ to achieve exact specifications of the stimulus, whether it be optical or acoustical. It was important to produce stimuli in precise and repeatable circumstances. One needed exact numbers to formulate exact laws of perceptual experience. This imperative lies as well behind the synthetic side to Helmholtz’s experimental practice in sensory science—the creation of sensible phenomena with precision instruments. The goal was to simulate artificially phenomena as sensibly similar to their natural analogues as possible. Not only was pure instrumental innovation crucial, but so was the attempt to link mathematical theory of the stimulus with precise instrumental realizations.

As mentioned, many have observed that Helmholtz’s inquiries into vision and hearing divide perceptual experience into three components: physical signals, physiological signs, and psychological percepts (Turner 1977a & b, 1993, Vogel 1993, Hatfield 1990). He aimed to trace the law−like relations between each member of the three realms (e.g. physical stimulus to physiological code), but also within each realm (physical to physical or psychical to psychical − over time). This framework called for a rigorous experimental foundation not achievable using standard musical instruments. Though musical instruments produce great sound, the richness of sound is largely a function of its complexity. To establish the relations he pursued he required uniform tones of great simplicity. This called for some ingenuity (with the help of Rudolph König, and other predecessors) to develop new instruments to produce pure tones (with simple sinusoidal wave−forms). These allowed him to control and specify the frequency of vibrations of each tone. Further, he needed instruments to aid the precise and exact perception of tones. Specifically, he needed help to focus on particular frequencies in a mass of tones.

If Helmholtz could simulate effects very closely, then the properties could be “heard” to match phenomena produced by the human voice, or common musical instruments. This attempt at simulation was both a complement to and made possible by the physical studies of musical instruments he had completed prior to the publication of the *Sensations of Tone* in 1863. These included work on organ pipes, the motion of violin strings, and the human voice. In *Sensations of Tone* he added detailed analyses of the physics of these instruments as well as reed pipes, piano strings, and plucked strings. This work was crucial to the analogical argument from the synthesis of tones. Despite much progress, he himself admits of limitations with respect to this highly complicated issue.

His extensive experiments employed a range of newly developed or adapted instruments to produce tones and others to aid the perception of tones. Of these instruments and experiments, my focus here will rest upon those he used in his research on vowel tones. He developed an electromagnetic tuning fork series to synthesize vowels (**Figure 1**). He used his well−known ear–fitted spherical resonators to amplify upper partials (harmonics) from the complex tones of human speech (**Figure 2**). Also important was his use of tuned resonating boxes to amplify tuning fork tones at the source **(Figure 3)**.

His argument for the nature of vowel tones is a premise in a larger argument. Vowels are one case of a more general class of tonal timbre. Helmholtz attempted to "prove" that timbre follows exclusively from the number, pitch, and amplitude (relative strength) of upper partial tones. Timbre or tone quality distinguishes tones of equal pitch produced by different instruments − e.g. a violin and a saxophone. This explanation of timbre is obviously not the sort of generalization (or law) that arises from normal perception of tones, nor subject to test by the unaided senses. As R. Steven Turner (1977) has argued, the project implicitly appeals to the lessons of the larger theory of perception. But many issues and techniques were inherited by Helmholtz in a developed, though unsettled state.[8] So his approach combines the state of the art and the lessons of his own view on perception. The perception theory with its empirical foundation suggested the promise of the research approach, and more specifically that the instrumental innovations were a necessary part of its success.

Some upper partial tones produced by musical instruments could be heard by trained musicians, and even by non−musicians listening carefully. Helmholtz claimed to hear up to sixteen partials using thin strings with particularly strong harmonics. Generally, as the harmonic numbers increased their intensity diminished, as did the intervals between the relative pitch. Helmholtz's ear−fitted, tuned resonators extended the range of perception to the higher partials. With vowel tones the need was acute because of the particular difficulty of hearing upper partials in the human voice. He believed speech perception to be particularly pragmatic, where normal processing highlights only those properties which suffice for the identification of the object, in this case the vowels (1863/77, 104). His resonators were tuned to specified frequencies allowing him to analyze the frequencies of the upper partials.

The experimental argument first established the general plausibility of explaining the character of vowels

8 See Vogel 1993 and Turner 1977, Boring 1942 for review of the background to Helmholtz's work. For a discussion of the philosophical issues in his acoustics see Hatfield 1993.

by appeal to a set of characteristic partials.[9] Helmholtz had experimented in the production of tones amplified by resonator boxes. In some cases he used resonators tuned not to the prime tone of a complex, but to one of the upper partials. This sound was of "a peculiar character, and more or less resembles one of the vowels of the human voice." (1863/77, 103) This might be expected, he argued, because vowels are tones produced by membranous tongues (vocal chords) amplified by a resonance chamber capable of altering its own dimensions and thus its pitch of resonance. This chamber (the mouth) can reinforce, at different times, different partials produced by the vocal chords

The early stages of the argument also emphasize analysis of the relevant mechanical properties of the different parts of human voice production. Vocal chord vibrations, the original source, produce discontinuous and sharply separated pulses of air. Represented as a Fourier series, they require a large number of terms and hence must "be received by the ear as a very long series of partials belonging to a compound musical tone." (1863/77, 103) Reed instruments (the closest analogy to vocal chords) he argued, produce a series of partials that uniformly decrease in intensity as the frequencies increase.[10] This pattern is altered as the compound tone produced by the vocal chords undergoes selective amplification by resonance as it passes through the mouth cavity. Using resonators he observed "the first 6–8 partials are clearly perceptible, but with very different degrees of force according to

9 Strutt (1896, 471) reports that R. Willis had experimented on vowels in the 1830s and proposed a similar upper partial hypothesis. Helmholtz addresses Willis' work (1863/77, 117−18)

10 Helmholtz more or less identifies pitch and frequency. I refer to physical tones by frequency and perceived tones by pitch.

the different forms of the cavity of the mouth . . . ." (1863/77, 104)

The ability to detect an extended range of partials in human vowels was only a first step. He needed to show that the mouth did in fact resonate at characteristic frequencies. An important next step then was specifying the characteristic resonance frequencies of various mouth cavity positions. He used methods similar to finding resonance frequencies of glass bottles and other enclosed resonating cavities. The technique was simple: strike tuning forks and hold them before the opening of the air chamber, in this particular case, and open human mouth. The louder the tone of the fork, the nearer it was assumed to match the proper tone of the chamber (mouth). He argued optimistically that the plasticity of the mouth allowed mimicry of the tone of any given tuning fork, and thus allowed exact determination of the shape the mouth must assume to resonate at that pitch.[11]

A detailed account of the functional anatomy of voice production follows including: properties of vocal chords, the mouth, tongue, and the lips. He analyzed their functions in terms of physical properties by simplification into analogous physical systems. But the analogy could not always be specified in precise physical terms. His argument amounted to this, if the components of the voice system function exactly as their physical analogues, then human vowels would fit his hypothesis. But in this case, analysis and analogy were insufficient, so he turned to synthesis or simulation.

Helmholtz's most sophisticated effort to synthesize vowels was geared to show that phase−differences have no effect on vowel quality. His point rested on whether, "an alteration of quality ensued when force was constant but phase varied." So he needed simple tones "of great purity, which can have both their force and phase exactly regulated" (1863/77, 120) and these could best be obtained from tuning forks amplified by resonance chambers. He configured a series of tuning forks of different characteristic frequencies and was able to set them in constant uniform motion by driving them electromagnetically.[12] To keep the vibration strong, the current stream had to alternate periodically. This was done with an interrupter fork apparatus **(Figure 4)**.[13] Attached resonance chambers amplified the tones. He controlled the phase with a combination of adjustable lids in front of the aperture of the resonance chamber and the amplitude by altering the distance between the fork and the resonator. The series was connected to a single power source. When the whole system ran with the forks in a state of uniform

11 Translator Alexander Ellis adds a note (105) raising a potentially serious objection. He observes that the same irregular cavity of the mouth often approximately reinforces many different tones. In his phonetic research it was critical to determine his own mouth cavity resonances, but he failed in his every attempt − no doubt following the exact protocol here laid out by Helmholtz.

12 See **Figure 3** for a picture of one such fork−resonator−electromagnet apparatus. **Figure 1** shows a top−view of a series of such forks.

13 For a more complete description see Helmholtz 1963/77, 120−22 and 398−400 or Lenoir 1994.

motion and with the resonator lids open then he says he could produce in rapid succession, “different combinations of the prime tone with one or more harmonic upper partials having degrees of loudness, and thus produce tones of different qualities.” (1863/77, 123)

He says that human vowels tones were relatively easy to synthesize because they were “accompanied by comparatively little extraneous noise and show distinct differences of quality which are easy to seize.” (1863/77, 123) Because most vowels had relatively low characteristic upper partials, he could reach them with the frequency ranges of his forks. **E** and **I** exceeded his limits because the crucial partials for their identity possessed too high a frequency. He claimed success with **U, O, Ö,** though not exceedingly well with **A**. Once he had successfully synthesized various vowels, he could test the phase−change hypothesis by altering the aperture with a lid and making appropriate adjustments in the distance of the resonators from the forks. Closing the aperture changed the phase and intensity, but not the frequency. Distance changed only the intensity. So he could produce qualitatively indistinguishable (to his satisfaction) vowel tones with very different phase combinations. He accomplished this as well for tones of several musical instruments, such as organ pipes.[14] This, he thinks, should have settled the question; “the quality of the musical portion of a compound tone depends solely on the number and relative strength of its partial simple tones, and in no respect on their differences of phase.” (1863/77, 126)

14 See Silverman 1992 for a critique of the efficacy of Helmholtz’s instrumental demonstration to settle the issue. Strutt 1896 has an excellent discussion of responses to Helmholtz’s work in physiological acoustics, but is very good on criticisms of this particular issue.

Obviously the issue was not settled by these experiments and as Risset and Wessel (1999) tell us, continues today. Indeed, Helmholtz's experiments appear to have the very same structure of analysis and synthesis that they tell us is novel to their approach. The interest lies not in Helmholtz's powers of anticipation. It rests in the understanding to be achieved of the role of experiment in his theory of perception. The fact that he considered his simulation to be so convincing reveals the epistemic weight he attributed to the kind of technique it implemented. This was an effective way to probe the nature of sound and hearing despite the considerable limitations of our perceptual apparatus. But should he have been so confident in the results of a simulation? According to the sign−theory, different physical causes can be heard "as" the same vowel sound. Risset and Wessel (1999) discuss this problem briefly. Helmholtz's's simulation argument suggests that once one has built a vowel tone from its elements, then this should prove the law − i.e. that vowels are so constructed. But if his theory recognizes that there are multiple possible physical causes of the same sensory and perceptual experience, then one wonders what sense and to what degree the character of perceptual experience depends upon the nature of the physical stimulus. Sometimes Helmholtz suggests that since multiple types of stimulus can produce the "same" type of sensations then the character of the perception does not depend upon the stimulus.

But it does, and his theory says it should. Helmholtz's notion of the law−like stipulates that there must be univocal coordination among the various relata. However, his sign−theory depends upon there being systematic non−univocality, at least in terms of there being multiple ways to cause subjectively non−distinguishable sensations. So one will not expect univocality from the subjective to the objective. But he does think it's possible to univocally correlate physical properties with sensational properties. Thus given a tone of a specified frequency, and a working hearing system, there should be a sensation of a certain pitch. His simulation does not rule out vowel tones being caused by exotic sources such as computer designed electrode implants in the cochlea. Rather, it wants to establish a univocal coordination between types of physical stimulus impinging upon the ear and the subjective experience of a vowel tone. If the simulation works, it achieves at least that goal. But it does not (nor need it) univocally establish a cause, given a subjective experience of a vowel tone.

More specifically, if the artificial apparatus and the human voice produce roughly identical perceptions, then what is identical as far as the law−like is concerned? They are not identical objects − physically and visually. To the extent that the simulation produces the same sensory experience, it is the motions of the air molecules that are similar. In this case it is obvious that the nature of the physical stimulus works as a key link in the chain of explanation regarding perceptual experience. The case of vowel synthesis reveals the important role Helmholtz saw for the structure and content of physical signals.

The three different but complementary roles of experiment show the centrality of this concept in Helmholtz's philosophy and science of perception. I think they also suggest much about the role of experiment in his philosophy of science. Though a full defense calls for further elaboration, it seems fair to assert that a notion of the autonomy of experiment is built into his general epistemology. Any claim to knowledge will require a heavy dose of experimentation in its genesis. It goes without saying that elaboration and testing of any wide−ranging claim would require experimentation. This implies first that in Helmholtz's view, experiment will always be a part of the context and logic of discovery as well as that of justification. Further, as part of the context of discovery, experimentation will have to fulfill numerous roles. There will be exploratory experiments, experiments to measure specific quantities, and experiments to identify specific causal factors. An exact taxonomy awaits further study (see Heidelberger and Steinle 1998).[15] Yet if experiment truly plays these central roles (possibly others too) then it should play a much more significant role in the interpretation of his philosophical views in general. This should not be viewed as a single pair of lenses for interpreting his work, but as a needed corrective to the heavy reliance upon purely theoretical hermeneutic principles.

References

15 Specifically, Heidelberger 1998 explains the important ways in which experiments expand the notion of reality for which theory attempts to provide explanation. Steinle 1998 explores Ampère's use of exploratory experimentation. Each provides important clues for pursuing these notions in Helmholtz's work.

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