The Helmholtz – Hering debate in retrospect

Hermann von Helmholtz and Ewald Hering, two giants of nineteenth century visual science, spent most of their careers in acrimonious debate, with Helmholtz the empiricist pitted against Hering the nativist. The details of this debate have been described by Turner (1994).

Helmholtz (1821 – 1894) was influenced by the empirical philosophers, such as Hume, and saw his views as an antidote to German idealistic philosophy and vitalism. His allies included Bezold, Exner, von Graefe, and Nagel. His position is conveyed by the following quotation from volume 3 of his *Handbook of Physiological Optics* (1910/1962):

"The sensations of the senses are tokens for consciousness, it being left to our intelligence to learn how to comprehend their meaning ... The only psychic activity required for this purpose is the regularly recurrent association between two ideas which have often been connected before." (pages 533 – 535)

He weakened his case for empiricism by admitting that natural selection may also play a role. But he qualified this by stating: “In any event, even if this anatomical mechanism exists it is merely conducive, and not obligatory.”

Hering (1834 – 1918) was thirteen years younger than Helmholtz. His allies included Bielschowsky, Hillebrand, Mach, and Tschermak-Seysenegg. Like Helmholtz, Hering was opposed to vitalism but, while not denying the role of experience and learning, he insisted that basic sensory and perceptual mechanisms are innate and a product of evolution. In the foreword to his book *On the Theory of the Light Sense* of 1874 Hering wrote:

“that modern tendency in sensory physiology, which has found its most acute expression in the *Physiological Optics* of Helmholtz, is not leading us to the truth, and whoever wishes to open up new avenues of research in this area, must first free himself from the theories which now prevail.”

He argued that, just as earlier physiologists had explained troublesome phenomena in terms of vital forces, so today in treatises on physiological optics one sees invocations of the ‘psyche’ or ‘inference’. For Hering, this was tantamount to ‘spiritualism’ and the idealism that Helmholtz claimed to abhor. Hering looked forward to the day when physiological psychology, including the physiology of consciousness, would replace the descriptive tradition of ‘philosophical psychology’ which investigates the phenomena of sensation without regard for their organic basis.

In his Founder’s Day lecture at Berlin University in 1878 Helmholtz retorted in like manner,

“First of all, nativistic hypotheses about knowledge of the visual world explain nothing at all, but only assume that the fact to be explained exists, while at the same time rejecting the possibility of tracing this knowledge back to reliably established mental processes.”

There was a strange futility about their battle. It was fuelled as much by personal animosity as by scientific issues. They each made concessions to the other but remained unreconciled on what they regarded as the fundamental issue. But what that fundamental issue was became ever more vague, as exemplified by the conflict between the Young – Helmholtz trichromatic theory of colour vision and Hering’s opponent colour theory. We now know that both were right—Helmholtz at the level of receptors and Hering at the level of ganglion cells and beyond (De Valois and De Valois 1975). Helmholtz explained colour contrast in terms of unconscious inference while Hering appealed to
lateral interactions between sensory elements. In a recent editorial to this journal, Kingdom (1997) argued that there is some truth in both views.

In this editorial I discuss the battle between Helmholtz and Hering in the field of spatial vision. The battle involved three aspects of spatial vision: eye movements, visual direction, and binocular vision. It was a ding-dong battle, with Helmholtz sometimes winning a point and sometimes Hering.

In the debate about eye movements Hering held that the coordinated movements of the two eyes are innate. Helmholtz held that the eyes are separate organs which, in principle, may be moved wholly independently of each other. He argued that adherence to Donder’s and Listing’s laws is a habit acquired by the use of the eyes of an individual during his lifetime to facilitate clear and easy visual orientation. Once acquired and ingrained, however, the facility cannot be overridden by acts of will. But—Helmholtz argued—such movements are anatomically possible and, by using prism glasses that produce abnormal separation of the visual axes, we can induce the eyes to perform vertical or absolute divergences. He observed that, when sleepy, he saw double images of objects, indicating that the eyes had diverged vertically or cyclorotated. When fully awake, he could not perform these eye movements voluntarily (Helmholtz 1910/1962, page 59).

Hering responded sarcastically to this claim. He wrote:

“It is likely that the great Helmholtz in his dozing state, had simply failed to notice that he had allowed his head to nod to one side. This would produce the same result.” (Hering 1864)

Point for Hering. Helmholtz retorted:

“I did not make the mistake which he (Hering) attributes to me, and which even a person with little training in observing double images could scarcely be guilty; namely, the mistake of supposing that the images were on different levels when they were really side by side, simply because my head happened to be tilted!” (Helmholtz 1910/1962, footnote, page 59)

While Hering at first denied the existence of cyclovergence, he later agreed with Helmholtz that it exists (Hering 1879/1942). Point for Helmholtz.

We still debate about the extent to which three-dimensional movements of the eyes are determined by structural, neural, or experiential factors (Demer et al 1997; Raphan 1998).

In the debate about visual direction, Helmholtz reluctantly agreed with Hering’s analysis in which the direction of an object is perceived with reference to a cyclopean point midway between the eyes. Point for Hering. Neither protagonist mentioned that Ptolemy in the second century and Alhazen in the eleventh had proposed the same theory (Howard 1996; Howard and Wade 1996).

Helmholtz claimed that the fact that people with restored sight cannot recognise simple objects proves that spatial vision must be learned. But he admitted that the rapidity with which they learn to distinguish between shapes suggests that neighbouring retinal points are perceived as adjacent, a view very close to Hering’s theory. While we still debate about the visual capacities of people with restored vision, it seems clear that Hering was correct with regard to local sign (Mioche and Perenin 1986), but that Helmholtz was correct in asserting that object recognition requires considerable learning; a fact Hering did not deny. However, no amount of learning restores stereopsis (Tytla et al 1993) and people with restored sight often despair and revert to behaving as a blind person (Apkarian 1983; Carlson et al 1986). The vast literature on the effects of monocular and binocular deprivation proves that visual experience supplements innate processes in the development of basic visual mechanisms in the visual cortex, but that this experience must occur before a critical age (Howard and Rogers 1995).
Hering proposed that each point in each retina has a local sign composed of three space values: its elevation, azimuth, and depth. He developed the following theory of depth values. Points on the nasal retina have positive depth values and those on the temporal retina have negative values. Images with a positive depth value appear beyond the convergence plane, even when only one eye is open. Images with a negative depth value appear nearer than the convergence plane. The depth values of images falling on corresponding points in the two retinas are equal and opposite and the object that creates them lies in the horopter.

Hering produced evidence which, he claimed, supported his theory of depth values. He fixated a vertical wire and placed a second wire nearer and to one side, as shown in figure 1. He claimed that the image of the second wire on the nasal half of the left eye appears more distant than the fixation point and that the image on the temporal half of the right eye appears nearer than the fixation point (Hering 1865, page 341).

Helmholtz (1910/1962, page 1554) sarcastically retorted:

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"I have gazed at the pin so long and so fixedly that everything was extinguished by the negative afterimages. ... I have never been able to persuade myself that this phenomenon occurred in the main as it ought to occur according to the Hering theory; and I never should have ventured to lay the foundation of a new theory of vision on an observation made with images that are half-extinguished in this fashion. However, I admit that I may have been unskillful. Only, Mr. Hering will have to forgive me for not being able to say that I have been convinced by this 'overwhelming proof' of the correctness of his theory, as he put it. ... We are forced to conclude that those depth feelings, if they exist at all, are so weak and vague that their influence is negligible in comparison with factors derived from experience."
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Helmholtz argued that, according to Hering’s theory, the two halves of a wall should appear inclined in opposite directions when one eye sees only the nasal half and the other eye only the temporal half. But this does not happen. Hering abandoned his theory of retinal depth values after this attack and adopted Helmholtz’s view that stereopsis is based on binocular disparity. Point for Helmholtz.

In the debate about binocular vision, Hering believed that binocular correspondence is innate, while Helmholtz (1873/1893, page 262) wrote:

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"We therefore learn that two distinct sensations are transmitted from the eyes, and reach consciousness at the same time and without coalescing; that accordingly the combination of these two sensations into a single perceptual picture of the external world is not produced by any anatomical mechanism of sensation, but by a mental act."
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Helmholtz was correct to reject the idea that inputs from corresponding points unite because, if this were so, disparity could not be detected. But in relegating disparity detection to higher processes he failed to consider the possibility of low-level disparity detectors, which we now know exist. In retrospect, Hering won this point.

Helmholtz claimed that the anomalous pattern of binocular corresponding points that develops in people with squint demonstrates the mutability of corresponding points. But Hering pointed out that because a system can be slightly modified this does not prove that it is not fundamentally innate. Point for Hering. The controversy about the cause of anomalous correspondence continues to this day. The traditional theory is that anomalous correspondence is an adaptation of the visual system to diplopia caused by strabismus. Another theory is that anomalous correspondence is the cause of strabismus rather than an adaptation to it (Kerr 1998). Yet another theory is that anomalous correspondence is due to abnormal innervation to the extraocular muscles, which alters the headcentric direction of stimuli in the strabismic eye relative to stimuli in the normal eye (Adler 1945).

Helmholtz claimed that vertical rods arranged along the horizontal horopter appear to lie in a frontal plane. Hering used this to support his theory of retinal depth values. Helmholtz was annoyed that his results were used to support Hering’s theory. He promptly repeated his experiment and claimed that vertical rods on the horopter appear in the frontal plane only at one distance, the abathic distance. Rods nearer than this appear to lie on a concave surface and rods further away appear to lie on a convex surface. He invoked an inferential process in which disparity is assessed in terms of perceived distance based on the unreliable cue of vergence.

Hillebrand, an ally of Hering, disagreed with this explanation. He proposed an explanation based on Kundt’s partition effect in which the half of a horizontal line imaged in the temporal retina appears longer than the half imaged in the nasal retina. He concluded that corresponding points are compressed in the temporal retinas relative to those in the nasal retinas. Figure 2 illustrates how this produces the deviation of the horopter at different distances.

Helmholtz rejected this explanation of the Hering–Hillebrand deviation and claimed that the Kundt partition effect does not indicate anything about the spacing of corresponding points. He argued that, when we bisect a horizontal line centred on the midline, the right half of the line is nearer to the right eye and projects a larger image to that eye. Similarly, the left half of the line produces a larger image to the left eye. When we bisect a line with only one eye open, we try to reproduce the familiar stimulus and produce the effect reported by Kundt (Helmholtz 1910/1962, pages 203–204). He explained the Hillebrand deviation derived from setting vertical rods in terms of a lack of reliable distance information. He showed that the deviation is no longer present when the vertical rods have dots along their lengths. He explained this by stating that dots allow the viewer to detect differences in the vertical dimensions in the images in the two eyes that occur away from the midline. These vertical disparities occur because an eccentric rod is nearer one eye than the other and, for a given eccentricity, vertical disparity increases with the distance of the rod. Vertical disparities thus supply distance information, which allows one to correctly assess the horizontal disparities in the rods and correctly set them to the frontal plane when required (Helmholtz 1910/1962, page 320).

Recently, Rogers and Bradshaw (1993, 1995) have shown that, indeed, people correctly set large random-dot displays to the frontal plane at all distances. They have also shown that, at near distances, vergence can supply the information for scaling horizontal disparities, as Helmholtz had suggested. It looks as though, in retrospect, Helmholtz won this point.
Although Helmholtz rejected the idea of relative horizontal compression of corresponding points, he believed that the vertical loci of corresponding points in the two eyes are relatively rotated outward by about $2^\circ$, which causes the vertical horopter to be inclined top away by an amount that depends on viewing distance. He believed that this effect is not innate but arises from our experience with ground planes and brings the ground plane into clear single vision. We now have evidence in support of this idea. Cooper and Pettigrew (1979) showed electrophysiologically that the corresponding vertical meridians of owls and cats are rotated by an amount that places the vertical horopter along the ground for the eye height and viewing distance of these animals. Point for Helmholtz.

Helmholtz became intensely annoyed by the battle with Hering and this may be why he returned to physics in 1875. In a letter to his friend, Emil du Bois-Reymond in 1865, he wrote:

“I find my work on binocular space perception a burden and ordeal. Like no other aspect of physiological optics, it draws me into philosophical questions about which it is impossible to persuade people of any definite answer.

Mr. Hering has annoyed me considerably with his impertinent ways of judging other people's work which, in part, he has not taken the trouble to understand properly. However, I do not want to treat him in a nasty way since he is an intelligent man in his own way. Even though, at the moment, his views conflict with mine, he is working out his own viewpoint in a consistent manner. He has been, as I have heard, mentally ill and this has until now held me back from bringing him down, which he has at times deserved.”

This may have been an unfounded rumour because we have no other information that Hering was ever mentally ill.

Figure 2. This illustrates how relative compression of points in the temporal retinas relative to those in the nasal retinas explains the change in shape of the horopter from convex to concave as the eyes converge.
Looking back we can say that Helmholtz won some battles and Hering won others. But is it possible to say who won the war? One aspect of the dispute between Helmholtz and Hering was tension between the desire to find physiological mechanisms underlying sensation and perception and the desire to construct abstract algorithms and functional explanations. That tension is still with us. Helmholtz had been too ready to relegate sensory processes to the mental sphere and give up the search for a physiological explanation. But he would be pleased with the resurgence of interest in cognitive factors in perception in the 1970s, with the emergence of computer-based algorithms of perceptual mechanisms, and with nerve-net models of perceptual learning. On the other hand, Hering would be pleased with the growth of our knowledge of receptive fields of retinal and cortical cells, and of the structure of lateral connections that possibly relate to contrast effects and our ability to detect connected edges.

The other aspect of the dispute was whether sensory and perceptual mechanisms are innate or learned. Hering stated that the only possible debate between nativists and empiricists can be over where to draw the line between inborn and stimulus capacities. But this view may be too simple. We now know that genetic and stimulus factors interact even in the embryo. Spontaneous discharges arriving from the retina help in the formation of connections in the growing visual cortex in the cat embryo (Catalano and Shatz 1998) and monkey embryo (Bourgeois and Rakic 1996). In neonate mammals, the effects of visual stimulation interact with a bewildering variety of genetically determined structures and processes in the formation of the receptive fields of cortical cells and of patterns of binocular interaction (Howard and Rogers 1995, chapter 15). Even in mature monkeys, visual stimulation induces a particular group of genes, known as immediate-early genes, to produce specific proteins in the visual cortex (Kaminska et al 1996). It is not a question of drawing a line between genetic and experiential factors but of understanding how they interact at different ages and at different levels of the nervous system.

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