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ABSTRACT

In the early 19th century the doctrine of identical retinal points, linked with the Vieth-Müller circle, was a pillar of German physiological optics. It was challenged by Wheatstone's observations of stereoscopic depth perception announced in 1838; he also advanced a cognitive theory of binocular vision that attacked physiological interpretations. In 1841 Brücke mounted a defense of the doctrine by questioning Wheatstone's observations and offering an alternative interpretation in terms of the integration over time of a rapid sequence of convergence eye movements. The theory could not be sustained because of evidence that stereoscopic depth occurred without eye movements. Brücke also questioned Wheatstone's observations that with some stereoscopic displays stimulation of identical retinal points could result in double vision. The binocular combination of circles differing in size was accounted for by differentially dissociating accommodation in opposite directions for each eye from convergence. Despite the negative reaction to Brücke's proposals, his speculations about the nature of rapid eye movements and of their neural basis were ahead of his time.

KEYWORDS

Brücke; Wheatstone; stereoscopic vision; convergence; eye movements

Ernst Wilhelm Brücke (1819–1892) was a medical student at the University of Berlin when he wrote the article on stereoscopic vision that has recently been translated;[1–3] he later became an assistant to Johannes Müller in Berlin. Brücke (Figure 1) was the first German physiologist to respond to the attack by Charles Wheatstone[4] on Müller's doctrine of identical retinal points; Brücke's article was published in the *Archiv für Anatomie und Physiologie* edited by Müller. Wheatstone's article was published in 1838 and a summary of it was translated into German in 1839;[5] a full translation into German (by August Franz, an ophthalmologist in London) appeared in 1842.[6] Brücke only cites the 1839 summary in his article but in the text he does mention an interaction with Dr. Franz "the translator of Wheatstone's article" and so it is likely that Brücke had access to the full translation before it was published in the following year.

In his 1838 article Wheatstone[4] described his invention of a reflecting stereoscope. The instrument opened up a new world for experimental investigations of binocular phenomena. With the stereoscope he was able to manipulate the pictures presented to each eye and observe the depth that was produced. In so doing, he found that: "the projection of two obviously dissimilar pictures on the two retinae when a single object is viewed, while the optic axes converge, must therefore be regarded as a new fact in the theory of vision. It being thus established that the mind perceives an object of three dimensions by means of the two dissimilar pictures projected by it on the two retinae, the following question occurs: What would be the visual effect of simultaneously presenting to each eye, instead of the object itself, its projection on a plane surface as it appears to that eye?" [4] (pp.372–373)

Binocular instruments were in existence long before the stereoscope was invented, as was knowledge of retinal disparities.[7,8] Indeed, Wheatstone described and illustrated the ways in which different stimuli could be viewed without a stereoscope by under- and over-convergence, by using two viewing tubes, or by a combination of over-convergence and a septum between the eyes. He, himself, was able to dissociate accommodation from convergence, and so did not require the instrument he invented; the stereoscope was devised so that others could view dissimilar pictures with ease. Having established that dissimilar pictures, when viewed in the stereoscope, produce the appearance of depth, Wheatstone conducted

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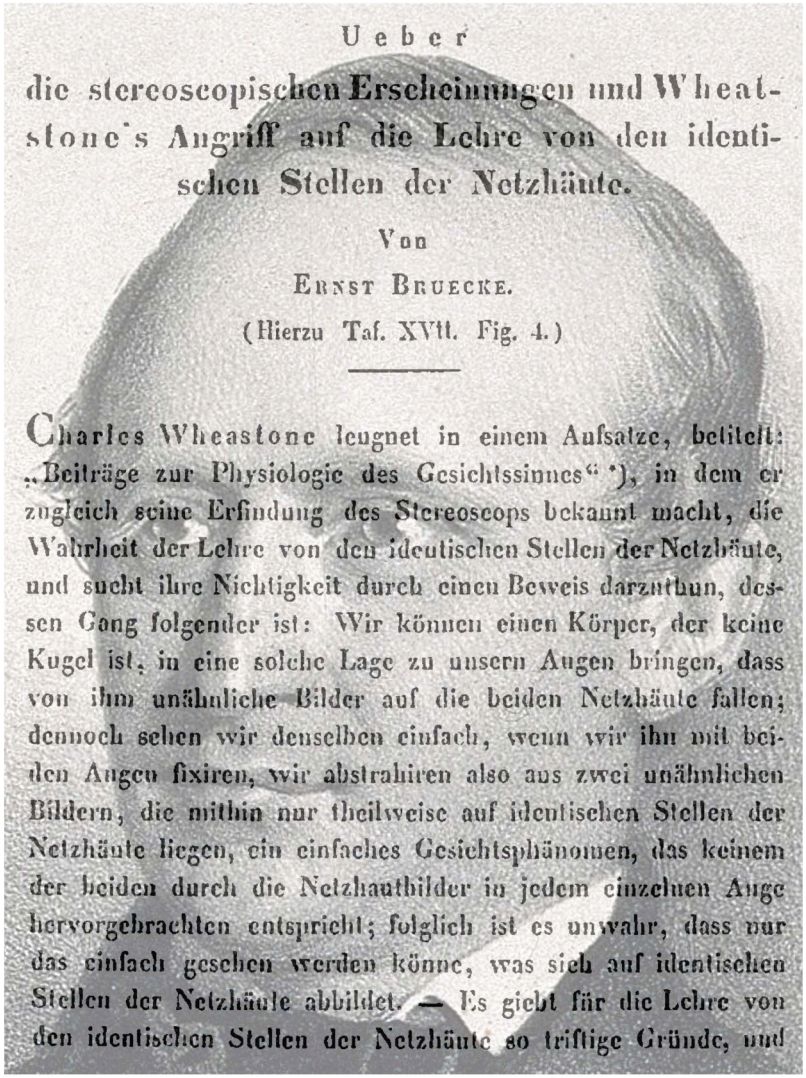

Ueber

die stereoscopischen Erscheinungen und Wheatstone's Angriff auf die Lehre von den identischen Stellen der Netzhäute.

Von

Ernst Bruecke.

(Hierzu Taf. XVII. Fig. 4.)

Charles Wheastone leugnet in einem Aufsatze, betitelt: „Beiträge zur Physiologie des Gesichtssinnes“ *), in dem er zugleich seine Erfindung des Stereoscops bekannt macht, die Wahrheit der Lehre von den identischen Stellen der Netzhäute, und sucht ihre Nichtigkeit durch einen Beweis darzuthun, dessen Gang folgender ist: Wir können einen Körper, der keine Kugel ist, in eine solche Lage zu unsern Augen bringen, dass von ihm unähnliche Bilder auf die beiden Netzhäute fallen; dennoch sehen wir denselben einfach, wenn wir ihn mit beiden Augen fixiren, wir abstrahiren also aus zwei unähnlichen Bildern, die mithin nur theilweise auf identischen Stellen der Netzhäute liegen, ein einfaches Gesichtsphänomen, das keinem der beiden durch die Netzhautbilder in jedem einzelnen Auge hervorgebrachten entspricht; folglich ist es unwahr, dass nur das einfach gesehen werden könne, was sich auf identischen Stellen der Netzhäute abbildet. — Es giebt für die Lehre von den identischen Stellen der Netzhäute so triftige Gründe, und

Figure 1. *Brücke's binocular vision* by Nicholas Wade. A composite portrait of Ernst Brücke together with the title page of his article on stereoscopic vision.

a series of systematic manipulations of the figures in order to discover the nature of the relationship. He demonstrated that the sign of disparity (crossed or uncrossed) determined the relative depth seen (nearer or farther), that there was a limit to the disparity yielding singleness of vision, that eye movements were not involved (because depth was seen in disparate afterimages), and that radically different pictures or colors resulted in rivalry. He also presented a stimulus suggesting that double vision could follow from stimulation of identical retinal points; it was called the “Wheatstone experiment” by Hering.[9,10] Brücke addressed these issues in his defense of Müller's doctrine and reached contrary conclusions in almost every case.

Brücke was more concerned with binocular single vision than stereoscopic depth and he commenced his refutation of Wheatstone in this vein: “There are such good reasons for the theory of the identical points of the retinas, and from it arise such important conclusions for the theory of vision, that it is of the greatest interest to investigate how it can be defended against Wheatstone's attack.”[2(p.111)] Similar sentiments were later voiced by Panum,[11] Volkmann[12] and Nagel.[13] The essence of Brücke's argument is that only a small (foveal) region of an object is clearly resolved at one time and the eyes move rapidly over an object with perception of it based on an integration of these fixations. In the case of solid objects or stereoscopic images it is variations in convergence that determine the

depth perceived. Thus, Brücke proposed a combination of rapid eye movements and visual persistence as the basis for stereoscopic depth rather than the stimulation of non-identical (or disparate) points. He stated that the theory was not novel and that its originator is unknown. Descartes[14,15] made an explicit link between convergence and apparent depth (Figure 2) as did many others thereafter.[8] However, Brücke added rapid changes in convergence and visual persistence to counter Wheatstone's theory.

The argument hinges critically on eye movements, as was appreciated by Wheatstone[4] who reported that stereoscopic depth could be perceived with afterimages (which are stabilized on the retina). Brücke repeated the experiment but did not experience depth; he even questioned Wheatstone's ability to maintain steady fixation. The issue was resolved in the year Brücke's article was published: Dove[16] illuminated stereoscopic pairs with an electric flash and saw depth. Volkmann[17] reached the same conclusion by presenting paired stimuli briefly in a tachistoscope.

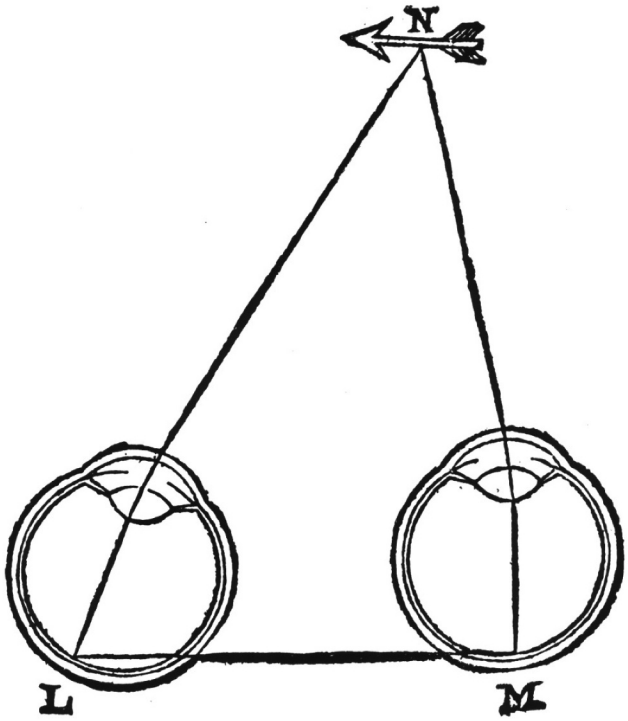

Figure 2. A diagram from Descartes[14] who described the influence of convergence on perceived distance: "...if the two eyes *L* and *M* are turned toward the object *N*, the magnitude of line *LM* and the two angles *LMN* and *MLN* will cause it [the soul] to know where point *N* is"[15(pp.62–63)].

Thus the argument that stereoscopic depth was dependent on rapid changes in convergence could not be sustained. Nonetheless, similar eye movement interpretations of stereoscopic depth were later proposed by Brewster,[18] Towne[19] and LeConte.[20]

Brücke did not measure the rapid changes of convergence that he speculated were the basis of stereoscopic depth, but he could have drawn on a phenomenon linking convergence to depth perception. What became known as the "wallpaper illusion" was described by Brewster[21]: the apparent depth of a regular, repetitive pattern depends on convergence. The phenomenon had been described earlier by Blagden,[22] but it was Brewster's analysis of it that gave it more widespread recognition. Brewster's theory of stereoscopic vision was very similar to that of Brücke, but no reference to Brücke was contained in it. Both opposed Wheatstone's cognitive interpretations for similar reasons – that the established principles of visual direction were rejected.

Brücke's speculations about rapid eye movements were very insightful; they predated by several decades experimental studies of eye movements, particularly by Hering[23] and Javal,[24] that established the saccade and fixation sequences that occur when reading. Both used afterimages as one of the methods to determine how the eye moves over text. Measuring rapid changes in convergence presented a far greater challenge as they are very small in comparison to version movements. Brücke maintained that such rapid eye movements occur all the time when observing objects in the environment. Moreover, he stated that the eye movements are unconscious. When attempting to maintain fixation on a stereopair, like the truncated cone illustrated in Wheatstone,[4] Brücke reported seeing double images contrary to Wheatstone's observation of singleness and depth. On the basis of this descriptive difference Brücke questioned Wheatstone's ability to fixate accurately; the contrary argument could be advanced.

Having outlined his theoretical interpretation of stereoscopic depth perception, Brücke proceeded to describe the experiments he conducted. Perhaps the only area of agreement with Wheatstone was in the descriptions of binocular

contour rivalry, both in terms of its phenomenology and the fact that it does not contradict the theory of identical retinal points. He used the same rivaling stimuli as Wheatstone – different letters to each eye surrounded by common circles. Panum[11] introduced the stimuli that are still used to examine rivalry – orthogonal gratings presented to different eyes.

Of Wheatstone's twelve paired drawings, eleven were used to demonstrate that stimulation of the two eyes with slightly different pictures could lead to depth perception. The odd one was the "Wheatstone experiment;" it involved presenting a thick vertical line to the right eye and a thick inclined one with a thin vertical to the left eye (Figure 3) and was taken to show "that similar pictures falling on corresponding points of the two retinae may appear double and in different places"[4(p.384)]. Wheatstone reported that the thick lines combined to be seen in depth and the thin line remained visible and vertical. That is, the vertical lines, falling on identical retinal points, were not combined. He also described, but did not illustrate, images of different magnitude in each eye like circles or squares and found that they were seen as single as long as the differences were not too large. These were the final two topics considered by Brücke and in the second case he examined the binocular combination of circles differing in diameter.

Brücke disagreed with Wheatstone's description and introduced a change to the stimulus adding a second, thin vertical line. Without an illustration, it is difficult from Brücke's text to reconstruct the stimulus he used nor is it evident whether the common surrounding square was retained. Indeed, many of the later attempts to repeat the experiment[9,11–13] changed the stimulus in some way and while most could not see what Wheatstone saw there were disagreements between them. When experiments[10] to replicate Wheatstone's conditions as closely as possible were conducted the results were not clear cut; large individual differences were obtained some reflecting Wheatstone's description and some corresponded to those of Brücke and others.

Wheatstone reported that when circles of slightly different diameters are viewed in the stereoscope they are seen as a single circle of an intermediate diameter. He even suggested experimental procedures that could determine the limits of size that can be combined. Brücke could not account for the single appearance of the circles with his convergence hypothesis and speculated that the accommodative states of the eyes change independently to produce this. He acknowledges that such a mechanism contradicts the linkage between convergence and accommodation that was established by Porterfield[25] (who introduced the term accommodation) and was confirmed by many others, including his mentor, Müller.[26] Unlikely as it was,

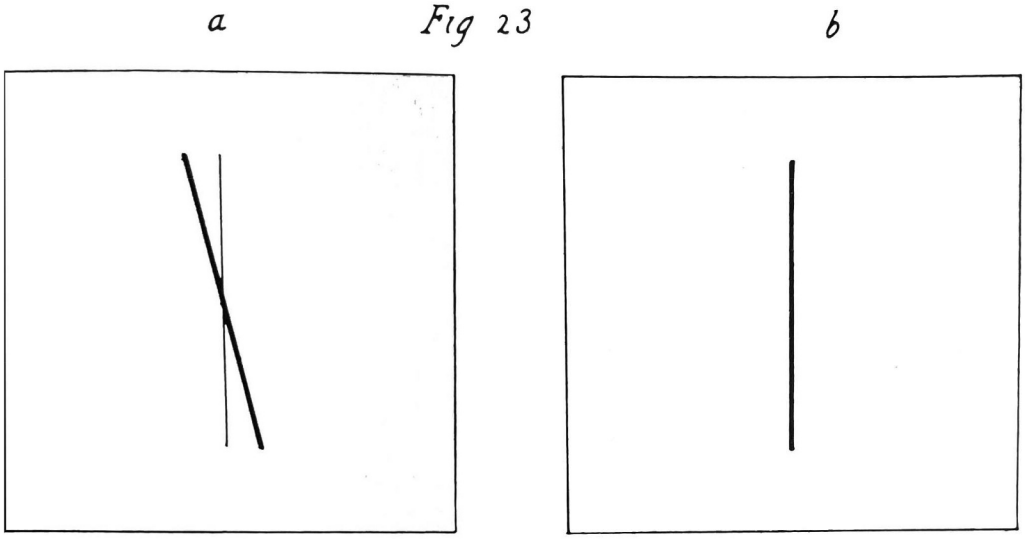

Figure 3. Wheatstone's illustration for what became called the 'Wheatstone experiment.' The images would have been reversed by reflection in the mirror stereoscope.

it seemed as though it was the only hypothesis that Brücke could advance in order to retain the doctrine of identical retinal points for binocular combination of objects differing in size.

If eye movements are implicated in the perception of depth then there should be some mechanism for taking them into account. Brücke addressed this at the end of his article and cited a case in Charles Bell's[27] book. Far better evidence for the involvement of the eye muscles in visual direction was provided by Bell[28] later and by Wells[29] much earlier; both showed that the direction in which an object appeared was dependent on the actions of the extraocular muscles. Nonetheless, Brücke's speculations on the likely interactions in the nervous system that could control such interactions were prescient.

Brücke[1] articulated the problems posed by stereoscopic depth perception based on retinal disparities for Müller's theory of single vision as a consequence of stimulating identical retinal points. Brücke proposed a theory of stereoscopic depth based on the integration of rapid changes in convergence but it could not be sustained following the demonstration of stereoscopic depth without eye movements. Nonetheless, Brücke's speculations about the nature of rapid eye movements and of their neural basis deserve greater recognition than they have so far received.

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References

1. Brücke EW. Ueber die stereoskopischen Erscheinungen und Wheatstone's Angriff auf die Lehre von den identischen Stellen der Netzhäute. *Archiv für Anatomie, physiologie und Wissenschaftliche Medicin*. 1841;8:459–476.
2. Brücke EW. About the stereoscopic phenomena and Wheatstone's attack on the theory of the identical points of the retinas. Part 1. *Strabismus*. 2022;30:111–113. doi:10.1080/09273972.2022.2069336.
3. Brücke EW. About the stereoscopic phenomena and Wheatstone's attack on the theory of the identical points of the retinas. Part 2. *Strabismus*. 2022;30:165–170. doi:10.1080/09273972.2022.2069336.
4. Wheatstone C. Contributions to the physiology of vision.—Part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision. *Philos Trans R Soc London*. 1838;128:371–394.
5. Wheatstone C. Ueber das Sehen mit zwei Augen und das Stereoskop. *Annalen der Physik und Chemie*. 1839;47:625–627. doi:10.1002/andp.18391230813.
6. Wheatstone C. Beiträge zur Physiologie des Gesichtssinnes. Erster Theil. Ueber eine merkwürdige und bis jetzt unbeachtete Erscheinung beim Sehen mit beiden Augen. *Annalen der Physik und Chemie*. 1842;1:1–48. Supplementary Volume. doi:10.1002/andp.18421310102.
7. Wade NJ. On the late invention of the stereoscope. *Perception*. 1987;16:785–818. doi:10.1068/p160785.
8. Wade NJ. *A natural history of vision*. Cambridge, MA: MIT Press; 1998.
9. Hering E. *Beiträge zur Physiologie. Volume 2*. Leipzig: Engelmann; 1862.
10. Ono H, Wade NJ. Resolving discrepant results of the Wheatstone experiment. *Psychol Res*. 1985;47:135–142. doi:10.1007/BF00309264.
11. Panum PL. *Physiologische Untersuchungen über das Sehen mit zwei Augen*. Kiel, Germany: Schwerssche Buhhandlung; 1858.
12. Volkmann AW. Die stereoskopischen Erscheinungen in ihrer Beziehung zu der Lehre von den identischen Netzhautpunkten. *Archiv für Ophthalmologie*. 1859;5:1–100.
13. Nagel A. *Das Sehen mit zwei Augen, die Lehre von den identischen Netzhautstellen*. Leipzig: Winter; 1861.
14. Descartes R. Traité de l'homme. In: Adam C and Tannery P, eds. *Oeuvres de Descartes*. Vol. 11. Paris: Cerf. 1664 [1909]; pp. 119–215.
15. Hall TS. *Treatise of Man. René Descartes*. Cambridge, MA: Harvard University Press; 1972.
16. Dove HW. Die Combination die Eindrücke beider Ohren und beider Augen zu einem Eindruck. *Monatsberichte der Berliner preussische Akademie der. Wissenschaften*. 1841;41:251.
17. Volkmann AW. Das Tachistoskop, ein Instrument, welches bei Untersuchung des momentanen Sehens den Gebrauch des elektrischen Funkens ersetzt. *Berichte über die Verhandlungen der Leipziger Gesellschaft der Wissenschaften*. 1859;11:90–98.

18. Brewster D. On the law of visible position in single and binocular vision, and on the representation of solid figures by the union of dissimilar plane pictures on the retina. *Trans R Soc Edinburgh*. 1844;15:349–368. doi:10.1017/S0080456800030040.
19. Towne J. Contributions to the physiology of binocular vision. Section VIII. *Guy's Hosp Rep*. 1869;14:54–83.
20. LeConte J. *Sight: An exposition of the principles of monocular and binocular vision*. New York: Appleton; 1869.
21. Brewster D. On the knowledge of distance given by binocular vision. *Trans R Soc Edinburgh*. 1844;15:663–674. doi:10.1017/S0080456800030246.
22. Blagden C. An appendix to Mr. Ware's paper on vision. *Philos Trans R Soc*. 1813;103:110–113.
23. Hering E. Über Muskelgeräusche des Auges. *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien. Mathematisch-naturwissenschaftliche Klasse*. 1879b;79:137–154.
24. Javal LÉ. Essai sur la physiologie de la lecture. *Annales D'Oculistique*. 1879;82:242–253.
25. Porterfield W. *A treatise on the eye, the manner and phaenomena of vision*. Edinburg: Miller, Hamilton and Balfour; 1759.
26. Müller J. *Zur vergleichenden Physiologie des Gesichtssinnes des Menschen und der Thiere nebst einem Versuch über die Bewegungen der Augen und über dem menschlichen Blick*. Leipzig: Knobloch; 1826.
27. Bell C *The anatomy of the human body*. Vol. 3. London: Longman, Rees, Cadell and Davies; 1803. (Reprinted in NJ Wade (Ed.) *The emergence of neuroscience in the nineteenth century*. Vol. 1. London: Routledge/Thoemmes Press; 2000.)
28. Bell C. On the motions of the eye, in illustration of the uses of the muscles and of the orbit. *Philos Trans R Soc*. 1823;113:166–186.
29. Wells WC *An essay upon single vision with two eyes: together with experiments and observations on several other subjects in optics*. London: Cadell; 1792. (Reprinted in Wade NJ. (2003a). *Destined for distinguished oblivion: the scientific vision of William Charles Wells (1757-1817)*. New York: Kluwer/Plenum; 2003.)