NOTES AND DISCUSSIONS

HELMHOLTZ AND THE THREE-COLOR THEORY: AN HISTORICAL NOTE

The historians emphasize Helmholtz's espousal of Thomas Young's theory of color vision but the fact is Helmholtz was at first none too certain about the correctness of what we now call the "Young-Helmholtz theory." Even Boring is wrong in thinking that Helmholtz accepted the theory with alacrity in 1852.[1] Helmholtz was still slightly dubious of it as late as 1860, and in 1852 had actually rejected the three-color theory. The following quotation from his 1852 paper,[2] which was translated and published in its entirety in the *Philosophical Magazine* in England during the same year,[3] clearly shows Helmholtz's position at that time.

Hence if we propose to ourselves the problem of imitating the colours of the spectrum by the union of the smallest possible number of simple colours, we find

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[1] In his most recent volume on the history of experimental psychology (*Sensation and Perception in the History of Experimental Psychology*, 1942, 1-613) Boring makes the following statements concerning Helmholtz's sponsorship of the three-color theory:

"In 1852, when he first adopted Thomas Young's theory of color, Helmholtz posited three specific visual energies" (p. 73).

"Quite early (1852) he brought forth and championed Thomas Young's theory of color, developing it as a theory of three specific nerve energies" (p. 119).

"Helmholtz (1852) in reviving Young's theory, threw the weight of his opinion toward three physiological processes, a principle accepted by most theorizing today as fundamental" (p. 128 f.).

"Helmholtz's theory had held the field after 1852" (p. 173).

"Helmholtz advertised Thomas Young's views and formulated the three-color theory in 1852. Clerk Maxwell supported Helmholtz" (p. 185).

"Until Helmholtz publicized it (Young's retinal theory of color) in 1852, however, it attracted scant attention" (p. 199).

"Although Helmholtz's experimental study of complementaries in 1852 is the first date for his espousal of the theory, the event was marred by Helmholtz's failure to find that he could get white from more than one binary combination" (p. 200).

Every one of these statements is in error. Helmholtz may indeed have "brought forth," "adopted," "championed," "revived," "advertised," "publicized," and "espoused" the Young theory, but to state that he did so in 1852 is incorrect. The "espousal" of the theory, moreover, was not "marred" in 1852 by a minor experimental failure. On the contrary, Helmholtz's experimental results at that time led him rather to reject the three-color theory.

[2] Helmholtz, Ueber die Theorie der zusammengesetzten Farben, *Ann. Phys. Chem.*, 163, 1852, 45-66, (Ser. 2, v. 87). Also in *Arch. Anat. Physiol. u. wiss. Med.*, 1852, 461-482; and reprinted in his *Wissenschaftliche Adhandlungen*, 2, 1883, 1-23.

[3] *Op. cit.*, Ser. 4, 4, 1852, 519-534. Communicated by John Tyndall.

at least five of the latter necessary for this purpose, namely red, yellow, green, blue, violet. I must, however, leave the question undecided, whether these are completely sufficient, and whether with better apparatus, which would permit of the illumination of larger surfaces by the simple colours, and by the corresponding compound ones placed adjacent, a practised eye might not detect differences which with my apparatus could not be recognized. If, however, we wish to limit ourselves to three colours, it would be best to choose the three simple ones which admit of the least perfect imitation, namely red, green, and violet: we should then obtain a yellow and blue, which, when compared with the colours of our pigments, would appear saturated, but which would not bear comparison with the yellow and blue of the spectrum. These are the three which Thomas Young proposed as the three primitive colours. Red, green, and blue would not answer so well; for were these three chosen, the mixed violet would appear worse than the mixed blue of the former three. The three primitive colours commonly chosen are altogether insufficient, because from them green can never be obtained.

According to the above we must also abandon the theory of three primitive colours, which, according to Thomas Young, are three fundamental qualities of sensation.[4] If the sensation of yellow by the yellow rays of the spectrum were due to the fact that by them the sensations of red and green were simultaneously excited, and both working together produced yellow, exactly the same sensation must be excited by the simultaneous action of the red and green rays; nevertheless by the latter we can never obtain so bright and vivid a yellow as that produced by the yellow rays. The same remarks apply to blue, which would be formed from the mixture of green and violet; and to violet, which would be formed from a mixture of blue and red. *To retain in this sense the theory of primitive colours, five such, at least, must be assumed.* On the contrary, to represent and classify the dull and comparatively impure colours of natural bodies, in the sense of Lambert and Forbes, three primitive colours would be quite sufficient. But, for a sure and scientific classification, it would be necessary to apply a method of combining colours different from the mixing of pigments.[5]

Nor is there explicit acceptance of the three-color theory in Helmholtz's two succeeding papers which appear in 1855 and 1858. In the 1855 paper there is no mention of the Young theory or, for that matter, of any other physiological theory. In his paper, entitled "Ueber die Zusammensetzung von Spectralfarben,"[6] Helmholtz demonstrated the existence of exact complementaries for a number of colors, thus extending his earlier work in which he had found only one pair of complementary colors; namely, yellow and indigo-blue.

Helmholtz's rejection of the Young theory in 1852 had been based on his inability to obtain by spectral mixture, colors as highly saturated as pure spectral colors. In 1858, he discusses the results of experiments on after-images which were intended to test a postulate which he assumed to be basic to the Young theory.[7] Maxwell, in his explicit adoption of the

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[4] Italics ours. The original reads: "Wir werden demnach auch die Lehre von den drei Grundfarben, als den drei Grundqualitäten der Empfindung, wie sie Thomas Young aufgestellt hat, fallen lassen müssen." (*Wiss. Abhandl.*, 2, 1883, 21.)

[5] Italics ours; *op. cit.*, 532-533.

[6] *Op. cit., Ann. Phys. Chem.*, 170, 1855, 1-28; reprinted in *Wiss. Abhandl.*, 2, 1883, 45-70.

[7] Helmholtz, Ueber die subjectiven Nachbilder im Auge, *Verh. d. naturhist. Ver. zu*

Young view in 1855, had postulated three elementary color sensations of greater saturation than those experienced in viewing the spectrum, and had even suggested a means for obtaining supersaturated color sensations: "It may be possible to experience sensations more pure than those directly produced by the spectrum, first by exhausting the sensibility to one color by protracted gazing and then suddenly turning to its opposite."[8] In his 1858 paper, Helmholtz reports the experimental production, in just such fashion, of sensations more saturated than the spectral colors, and he observes that their existence is necessary for the Young theory to be correct.

In a short paper, published in 1859,[9] Helmholtz briefly indicates that Young's theory can be used to reduce the multiplicity of color phenomena to simple principles; he confirms Maxwell's findings on the color equations of the color blind and suggests an explanation of color blindness in terms of the Young theory; and finally, he sees in the study of the color mixture data of these individuals a means for determining the *Grundfarben.*

A fuller development of the three-color theory came only in 1860 with the publication of Volume II of the *Handbuch der physiologischen Optik.*[10] König summarizes the development of, and the changes in, Helmholtz's position in relation to the theory in the following statement.

> The extent to which the recognition of Young's views was bound up with the advance of experimental results is indicated by the fact that even Helmholtz at first (*Pogg. Ann.* 87, p. 45 and Müller's *Archiv.,* 1852, p. 461) believed he saw in the observed facts an incompatibility with these views, while soon afterwards, on the basis of additional investigations, (*Verb. des naturhist. med. Vereins zu Heidelberg,* 2, 1859, 1; *Handbuch der physiol. Optik,* 1st edit. Par. 20) he acknowledged Young's theory completely.[11]

Helmholtz's shift in position with regard to the three-color theory is of interest today, particularly in view of recent experimental developments. A multiple-receptor, or polychromatic color mechanism is suggested by Granit's work in electrophysiology[12] and by Hartridge's microstimulation studies.[13] The shift, on the part of a few investigators, away from the

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Rheinland u. Westphalen, 15, 1858, 98-100; reprinted in *Wiss. Abhandl.,* 3, 1895, 13-15.

[8] J. C. Maxwell, On the theory of colours in relation to colour-blindness, in George Wilson's *Researches on Colour-Blindness,* 1855, 153-159.

[9] Helmholtz, Ueber Farbenblindheit, *Verh. d. naturhist. med. Ver. zu Heidelberg,* 2, 1859, 1-3; reprinted in *Wiss. Abhandl.* 2, 1883, 346-349.

[10] *Op. cit.,* Cf. Section 20.

[11] Our translation; for original see Ueber die neuere Entwickelung von Thomas Young's Farbentheorie, *Naturwiss. Rundschau,* 50, 1886, 457-464. Reprinted in König's *Collected Works,* 1903, 88-107, cf. 91.

[12] R. Granit, *Sensory Mechanisms of the Retina,* 1947, 1-391.

[13] H. Hartridge, Recent advances in color vision, *Science,* 108, 1948, (no. 2807), 395-405.

simple three-component and towards some form of polychromatic theory is, ironically enough, a return to Helmholtz's original position. Indeed, one of the arguments used to support a polychromatic view is the very one concerning the desaturation of mixture colors upon which Helmholtz based his original rejection of the Young theory.[14] We may yet find that Helmholtz's original straightforward interpretation is to be taken at face value, and that, rather than accepting the theory of a three-receptor mechanism with its assumption of hypothetical, unreal primaries derived through mathematical treatment of color-mixture data, a more adequate physiological view than has hitherto been presented will be forthcoming to explain all the facts.

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MEYER'S THEORY OF THE MECHANICS OF THE INNER EAR

I am writing this note, on the fiftieth anniversary of my theory of the mechanics of the cochlea, to reaffirm the hypothesis and to point out that nothing has been discovered during the years since its formulation to cause me materially to modify it. The theory, finally proposed in 1898[1] after a preliminary announcement in 1896,[2] has been completely misunderstood and grossly misrepresented.

My theory *rejects* the hypothesis that any part of the cochlea is under permanent tension; it holds that the *analysis* of a compound sound occurs in the cochlea—not in the brain as Fletcher misrepresents me;[3] it insists that sensory analysis is prepared by the purely hydraulic (opposed to kymographic) functioning of the cochlea; and it replaces the hypothesis of resonance (which is impossible without permanent tension) by a simple

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[14] Hartridge, *op. cit.*, 397-398.

[1] Max Meyer, Zur Theorie der Differenztöne und der Gehörsempfindungen überhaupt, *Zsch. f. Psychol. u. Physiol. d. Sinnesorg.*, 16, 1898, 1-34; Ueber die Intensität der Einzeltöne zusammengesetzter Klänge, *ibid.*, 17, 1898, 1-14.

[2] Meyer, Ueber Kombinationstöne und einige hierzu in Beziehung stehende akustische Erscheinungen, *ibid.*, 11, 1896, 177-229. Here is found the principle of *geometrical dissection* of a compound curve. The first outline, very brief, of the *mechanical function* is found in Ueber die Funktion des Gehörorgans, *Verh. d. physik. Gesellschaft*, 17, 1898, 49-55.

[3] G. O. Russell (*Speech and Voice*, 1931, 28 f.) quotes from Harvey Fletcher (Physical measurements of audition and their bearing on the theory of hearing, *J. Franklin Inst.*, 196, 1923, 289-326) the following: "Meyers in his theory stated . . . pitch discrimination is accomplished in some way in the brain." Regarding Fletcher's statement, Russell comments: "Meyer emphatically denies this. . . . The cochlea is the analyzer." Fletcher has never corrected his misstatement.