$$\begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array}.$$

The successive powers of V would be:

$$V^{(2)} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array} \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \end{array}$$

$$V^{(3)} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array} \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \end{array} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \end{array}.$$

$$V^{(4)} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array} \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \end{array} = \begin{array}{c@{}c} & \begin{matrix} a & b & c & d & e \end{matrix} \\ \begin{matrix} a\\ b\\ c\\ d\\ e \end{matrix} & \begin{bmatrix} 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \end{array}$$

A simple count of the number of unities in each row or column reveals the underlying order, which permits the permutation of rows and columns. Then the triangular pattern can be displayed:

$$\begin{array}{c@{}c} & \begin{matrix} c & a & e & d & b \end{matrix} \\ \begin{matrix} c\\ a\\ e\\ d\\ b \end{matrix} & \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array}.$$

In a practical example, it would be very fortuitous to ask for exactly those 4 of the 10 possible comparisons. However, if somewhat more than 4 comparisons are made, the matrix can be completed as long as those 4 are among the ones made.

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On Colored–Hearing Synesthesia: Cross–Modal Translations of Sensory Dimensions

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This article reviews colored-hearing synesthesia, in which sounds induce visual images (photisms). Colored hearing manifests correlations between dimensions of auditory and visual experience. Two general findings are that (a) the brightness of photisms varies with the brightness (density) of the inducing sounds and (b) the size of photisms varies with the size (volume) of the inducing sounds. In colored hearing produced by speech sounds, the induced hues and brightnesses can be related to the formant structures of the vowels. Synesthetes align dimensions on different modalities in ways that are qualitatively similar to the ways that nonsynesthetes align them (e.g., in phonetic symbolism). Synesthesia appears to be a cross-modal manifestation of connotative meaning in a pure sensory form; its inflexibility (compared to language) makes synesthesia less significant in adulthood than in childhood.

One of the most curious and intriguing phenomena of the human mind is synesthesia—the translation of attributes of sensation from one sensory domain to another. Among the most commonplace of synesthetic perceptions are the well-known connections between color and thermal sensations: Yellow, orange, and red are frequently perceived and described as "warm" colors, blue and green as "cool" colors. A scheme of warm and cool colors was described a century ago (Sully, 1879).

Much more dramatic examples of synesthesia are the strong, often apparently idiosyncratic, associations reported in the literature on colored hearing and colored taste. One may read of a synesthete for whom violin music is represented as a dance of sparkling white and yellow stripes, or of another for whom the taste of vinegar conjures up bright greenness.

It is easy to dismiss synesthetic experiences as peculiar, rare, and idiosyncratic phenomena that seem to have little bearing on the operation of the "normal" mind. What, after all, is one to do with a report like that of Luria's (1968) subject S., the mnemonist cum synesthete:

> Presented with a tone pitched at 50 cycles per second and an amplitude of 100 decibels, S. saw a brown strip against a dark background that had red, tongue-like edges. The sense of taste he experienced was like that of sweet and sour borscht, a sensation that gripped his entire tongue. . . .
>
> Presented with a tone pitched at 2,000 cycles per second and having an amplitude of 113 decibels, S. said: "It looks something like fireworks tinged with a pink-red hue. The strip of color feels rough and unpleasant, and it has an ugly taste—rather like that of a briny pickle." (pp. 45–46)

There is no doubt that many synesthetic perceptions are peculiar and idiosyncratic. But many others are not. In particular, as I hope to demonstrate, the associations between color and sound are often regular, systematic, and consistent from one person to another. Rather than displaying merely some odd, fortuitous associations, these universal synesthetic experiences reflect important cognitive properties that in several respects are common to normal people as well as to synesthetes.

Colored Hearing

An attempt to review here the entire literature on synesthesia is impossible. Prior to the

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turn of the twentieth century, there had already been published several books and more than a hundred papers on the topic. The richest vein of material comprises the literature on *colored hearing:* Suarez de Mendoza's review, published in 1890, contains 59 references; Krohn's (1892), contains 85; Clavière's (1898), 131; Argelander's (1927), 466; and Mahling's (1926), 533.

By the end of the nineteenth century, colored hearing was such a popular topic that a committee of seven prominent psychologists was organized at the 1890 International Congress of Physiological Psychology; its purpose was to standardize the terminology of synesthesia and to advance scientific understanding. The members included the Swiss psychologist Flournoy (who, together with Claparède, compiled data on colored vowels) and the Rumanian Gruber. Gruber (1893), like Claparède and Flournoy, attempted a large-scale survey on colored hearing by means of a questionnaire; but alas, whereas Flournoy (1892) was able to obtain reports on color responses to vowels from over 200 synesthetes, Gruber obtained responses from only 23 (see Marinesco, 1912).

Reports on synesthesia, especially of colored hearing, began to mount during the mid-nineteenth century. For extensive reviews of early knowledge and opinion, the interested reader is referred to Krohn (1892), Clavière (1898), Argelander (1927), and Mahling (1926).[1] Several of the nineteenth-century accounts of synesthesia appeared in medical journals (e.g., Baratoux, 1887; Colman, 1894; Grafé, 1897; Hilbert, 1895; Pedrono, 1882; Quincke, 1890); to some scientists of the period, colored hearing seemed a medical oddity, if not a symptom of physiological abnormality (cf., Clavière, 1898). Indeed, it is of historical interest that the first scientific reference to synesthesia appears to be medical, namely, that of the turn-of-the-eighteenth-century English ophthalmologist T. Woolhouse (see Castel, 1735).

During the nineteenth century, evidence began to mount that implied colored hearing is is less likely a physiological perversity than a somewhat uncommon, but nonetheless interesting and important, psychological phenomenon. Galton's (1883) report on various forms of synesthesia, including colored hearing, helped to make the topic somewhat more "respectable"; and Fechner's (1876) and Bleuler and Lehmann's (1881) studies, by providing some quantification of the frequencies of occurrence of synesthetic perceptions, demonstrated the regular nature of cross-modal analogies. The last two studies noted in particular the potency of vowel sounds in the evocation of colors, although it is readily apparent even to the examination of the literature before 1876 that vowels are an especially powerful source for the production of secondary visual "sensations."

Colored Vowels

The fundamental question of concern here is: Do synesthetic experiences reflect some intrinsic sensory correspondences? With respect to colored hearing and particularly colored vowels, the question becomes: Is there an intrinsic relation between sound (vowel quality) and associated visual sensations (colors)? The evidence at hand suggests that there is a relation, and the theoretical position taken here is that the synesthetic relations between color and sound (vowel) quality are at least as intimate as is the well-studied relation between brightness and loudness in nonsynesthetic subjects. When people are asked to match brightness of lights to loudness of sounds, they align increasing luminances with increasing sound pressures in a systematic manner that is similar from person to person (Marks & J. C. Stevens, 1966; J. C. Stevens & Marks, 1965). Basically, then, the proposal set forth here is that synesthesia provides a form of systematic cross-modality matching.

Table 1 is a summary of reports and observations on colored hearing. One of the most interesting of the early statements is Arthur Rimbaud's (1871/1937) poem "Le Sonnet des Voyelles," in which the poet expressed the presumed colors of the cardinal vowels: "A noir, E blanc, I rouge, U vert, O bleu: voyelles,/ Je dirai quelque jour vos naissances latentes" (p. 93).

[1] Each author made good use of previous bibliographies, and some (e.g., Mahling, 1926) unabashedly listed works not verified. Although Mahling's list of references is most extensive, the reader is warned that it contains numerous errors.

TABLE 1

CHRONOLOGICAL SUMMARY OF LITERATURE ON VISUAL–AUDITORY SYNESTHESIA

Source	Date[a]	Description
Pythagoras	6th cent. B.C.	"Music of the spheres"
Aristotle	4th cent. B.C. (1931)	Harmony of colors like harmony of sounds
Arcimboldo[b]	16th cent.	Devised color music
Locke	1690	Blind man apprehends scarlet by sound of a trumpet
Leibniz	1704 (1896)	Blind man apprehends scarlet by sound of a trumpet
Newton	1704	Parallel between colors of spectrum and notes of musical scale
Woolhouse[c]	c. 1710	Synesthesia in a blind man
Castel	1725, 1735	Parallel between colors and musical notes; built color organ
Herder	1772	Natural connection of color and sound via feeling
L. Hoffmann[d]	1786	Report of colored music
E. Darwin	1790	Parallel between colors and musical notes
E. T. A. Hoffmann	1810 (1899)	*Kreisleriana:* colored music
Sachs[d]	1812	Report of colored vowels
Tieck	1828	*Schriften:* colored music
Gautier	1843, 1846	Description of colored hearing induced by hashish
Baudelaire	1857	"Correspondances"
Ludlow	1857	Description of colored hearing induced by hashish
Baudelaire	1860 (1923)	Description of colored hearing induced by hashish
Nahlowsky	1862	Description of colored hearing: pitch–brightness
Perroud[d]	1863	Report of colored vowels: physiological theory
Rimbaud	1871 (1937)	"Le Sonnet des Voyelles"
Wundt	1874	Equivalence of pitch and brightness is by analogy
Fechner	1876	Report of colored vowels
Bleuler & Lehmann	1881	Review of colored hearing and report of colored vowels: *law of brightness*, pitch–size, loudness–size
Mayerhaeusen[d]	1882	Report of colored vowels
Pedrono	1882	Report of colored music: pitch–brightness, loudness–brightness, physiological theory
Galton	1883	Report of colored vowels: synesthesia frequent in children
Hall	1883	Colored hearing frequent in children
de Rochas	1885	Report of colored vowels: pitch–brightness
Giradeau	1885	Report of colored hearing: pitch–brightness
Lauret[d]	1885, 1886	Report of colored vowels and music
Baratoux	1887	Report of colored vowels: pitch–brightness
Ghil	1887 (1938)	*Traité du Verbe:* system of colored vowels
Lauret & Duchaussoy	1887	Report of colored vowels
Albertoni	1889	Description of colored music: *auditory daltonism*
Raymond[d]	1889	Report of colored vowels
Klinckowström	1890	Report of colored vowels
Quincke	1890	Report of colored vowels
Suarez de Mendoza	1890	Review and report of colored vowels and music
Beaunis & Binet	1892	Report of colored vowels
Binet	1892	Report of colored vowels
Binet & Philippe	1892	Report of colored vowels
Flournoy	1892	Report of colored vowels
Krohn	1892	Review of colored hearing
Binet	1893	Colored hearing has associative basis
Calkins	1893	Report of colored vowels and music: associative theory
Flournoy	1893	Review of colored hearing and vowels: *law of brightness*
Gruber	1893	Questionnaire on colored hearing
Philippe	1893a	Report of colored hearing in the blind: pitch–brightness

TABLE 1—(*Continued*)

Source	Date[a]	Description
Philippe	1893b	Report of colored vowels
Starr	1893	Report of colored music: pitch–brightness
Colman	1894	Report of colored vowels: associative theory
Calkins	1895	Report of colored hearing: often pleasurable
Grafé	1897, 1898	Report of colored vowels
Clavière	1898	Review of colored hearing
Laignel-Lavastine	1901	Report of colored vowels: associative theory
Claparède	1903	Report of colored vowels: colored hearing stable over time
Dresslar	1903	Colored hearing stable over time: associative theory
Stelzner	1903, 1904	Report of colored vowels
Ulrich	1903	Report of colored vowels
Lemaitre	1904	Report of colored vowels
Lomer	1905	Report of colored vowels and music
Rossigneux	1905	Review of colored vowels from poetry
Smith	1905	Report of colored hearing: pitch–brightness
Harris	1908	Colored hearing has associative basis, hereditary tendency
Raines	1909	Report of colored music
Rose	1909	Report of colored hearing and vowels
Myers	1911	Report of colored music: pitch–brightness
Scriabin	1911	*Prometheus:* composition for sound and light
Hug-Hellmuth	1912	Report of colored vowels: psychoanalytic theory
Kandinsky	1912	Description of colored music
Marinesco	1912	Report of colored vowels and music
Schultze	1912	Report of colored vowels
Coriat	1913	Report of colored hearing and vowels
Langenbeck	1913	Report of colored vowels: associative theory
Wehofer	1913	Review of colored hearing and vowels: pitch–brightness is function of vowel formants
Langfeld	1914	Report of colored music: stable over time, pitch–brightness, physiological theory
Mudge	1920	Report of colored music: pitch–brightness
Wheeler	1920	Report of colored hearing: pitch–brightness, loudness–brightness
English	1923	Report of colored music: associative theory
Ginsberg	1923	Report of colored vowels and music: pitch–brightness
Henning	1923	Report of colored vowels: relations based on phonetic structure
Révész	1923	Report of colored hearing: frequent in children
Anschütz	1925	Report of colored music: pitch–brightness, pitch–size
Anschütz	1926	Report of colored vowels and music
Mahling	1926	Review of colored hearing
Argelander	1927	Review of colored hearing, report of colored vowels
Beringer[e]	1927	Report of colored hearing induced by mescaline: pitch–brightness
Collins	1929	Report of colored vowels
Voss	1929	Report of colored hearing: pitch–brightness, pitch–size, loudness–size
Vernon	1930	Report of colored music: pitch–brightness, pitch–size
Zigler	1930	Pitch–brightness, pitch–size
Hornbostel	1931	Brightness is universal attribute of sensation: pitch–brightness in nonsynesthetes
Ortmann	1933	Report and review of colored hearing: pitch–brightness
Kelly	1934	Attempt to teach colored hearing
Riggs & Karwoski	1934	Report of colored hearing: synesthesia is alignment of dimensions, pitch–brightness, pitch–size
Dudycha & Dudycha	1935	Report of colored music: pitch–brightness, pitch–size
Karwoski & Odbert	1938	Report of colored music: pitch–brightness, pitch–size
Leuba	1940	Report of conditioned sensation
Ellson	1941	Report of conditioned sensation
Aiken	1942	"Music"
Karwoski, Odbert, & Osgood	1942	Report of colored music
Odbert, Karwoski, & Eckerson	1942	Report of colored music
Howells	1944	Attempt to teach colored hearing
Reichart, Jakobson, & Werth	1949	Report of colored vowels: cross-linguistic similarity
Delay, Gérard, & Racamier	1951	Report of colored hearing induced by mescaline
Masson	1952	Report of colored vowels and music: brightness is function of formant spacing
Simpson, Quinn, & Ausubel	1956	Report of pitch–hue correspondences in nonsynesthetic children
Ulich	1957	Survey of synesthesia: colored music
Wicker	1968	Report of pitch–brightness correspondences in non-synesthetes
Marks	1974	Report of pitch–brightness and loudness–brightness in nonsynesthetes

Note. This summary includes reports, descriptions, and surveys, including general principles and explanations.
[a] Dates in parentheses indicate date in reference list.
[b] Cited in Eastlake, 1840.
[c] Cited in Castel, 1735.
[d] Cited in Suarez de Mendoza, 1890.
[e] Cited in Werner, 1940.

Later, Rimbaud (1873/1937) remarked that the colors of vowels were his *invention:*

> J'inventais la couleur des voyelles!—A noir, E blanc, I rouge, O bleu, U vert.—Je réglai la forme et le mouvement de chaque consonne, et, avec des rhythmes instinctifs, je me flattai d'inventer un verbe poétique accessible, un jour ou l'autre, à tous les sens. Je réservais la traduction. (p. 285)

As we shall soon see, there is general agreement on the part of synesthetes as to the colors of vowels, at least when these are reported in the scientific literature. Thus, we shall be able to decide how well the poet Rimbaud's invention agrees with more generally obtained results.

Most likely under the influence of Rimbaud, the poet René Ghil (1887/1938) attempted to build a scientific–literary system on the presumed colors of sounds. Ghil's system of vowel colors gave *a* as black, *e* as white, *i* as blue, *o* as red, and *u* as yellow. Note that the first two pairs are the same as those given by Rimbaud. In related vein, Rossigneux (1905), on the basis of an analysis of the sounds and images of poetry, also came to derive colors of vowels. His list gave *a* as white, *e* as green and blue, *o* as red, and *u* as black. As we can see, there is absolutely no overlap between Rossigneux's and Rimbaud's schemes and only small overlap between Rossigneux's and Ghil's. Note, however, that Rossigneux meant to limit the application of his scheme to sound–color relations in poetry.

That there exist some reliable correlations between sound composition and color is evident from Table 1. Reports by Nahlowsky (1862), Wundt (1874), de Rochas (1885), Giradeau (1885), Baratoux (1887), Philippe (1893a), Starr (1893), Smith (1905), Myers (1911), Langfeld (1914), Mudge (1920), Wheeler (1920), Ginsberg (1923), Anschütz (1925), Voss (1929), Vernon (1930), Zigler (1930), Ortmann (1933), Riggs and Karwoski (1934), Dudycha and Dudycha (1935), Karwoski and Odbert (1938), Wicker (1968), and Marks (1974) all include the observation of a correlation between auditory pitch and visual brightness. The higher the pitch (the higher the frequency) of a sound, the greater tends to be the brightness of the photism; as Suarez de Mendoza (1890) wrote, "Thus, they appear darker when they are struck on lower notes; but so much more clear and brilliant when they are formed of higher notes" (p. 140).

The importance of this observation lies not only in its content (i.e., in the particular correlation between hearing and vision) but also in the fact that it manifests an association between *dimensions* of auditory and visual experiences, not just associations between individual sensations. Synesthesia (colored hearing) consists not of random associations between isolated phenomena or qualities on two sensory domains, but rather expresses correlated dimensions or attributes. To the best of my knowledge, the first clear enunciation of this principle was made by Riggs and Karwoski (1934).

Mention should be made that high-pitched sounds, or more properly high-frequency sounds, are often described by nonsynesthetic subjects as *bright.* Hornbostel (1925, 1931) argued fervently for the universality of brightness as a dimension of all sensory experience. Colored hearing appears to be one embodiment of Hornbostel's principle: Bright sounds elicit bright photisms. This is discussed more fully later.

Analysis of vowel colors. Are there any other pairs of dimensions besides brightness and pitch that correlate in colored hearing? At this point, it becomes valuable to examine in detail the colors associated with various vowels. Even cursory examination of the literature shows that from one report to another, the same colors tend to be aroused by the same vowels. Consistency is nowhere near complete; nevertheless, it is strong and impressive.

In order to examine in as great detail as possible the colors ascribed to vowels, I have gathered together as many of the reports on vowel color as I could obtain. In addition to the large-scale studies of Fechner (1876), Bleuler and Lehmann (1881), and Claparède (reported by Flournoy, 1892, 1893), I tabulated results reported by Sachs, Perroud, Mayerhausen, Lauret, and Raymond (as compiled by Suarez de Mendoza, 1890) and by Galton (1883), de Rochas (1885), Baratoux (1887), Lauret and Duchaussoy (1887), Klinckowström (1890), Quincke (1890), Beaunis and Binet (1892), Binet and Philippe (1892), Philippe (1893b), Grafé (1898), Laignel-Lavastine (1901), Claparède (1903), Stelzner (1903, 1904), Ulrich (1903), Lemaitre (1904), Lomer (1905), Gruber (reported by Marinesco, 1912), Schultze (1912), Hug-Hellmuth (1912), Langenbeck (1913), Ginsberg (1923), Henning (1923), Anschütz (1926), Argelander (1927), Collins (1929), Reichard, Jakobson, and Werth (1949), and Masson (1952).

The classification of colors used to evaluate the synesthetic responses was: yellow, red, green, blue, violet, white, gray, brown, and black; that is, all colors were classified in terms of one or more of these categories. Occasional reports of other colors were subdivided appropriately among the nine color categories. For instance, each report of orange was divided up as .5 yellow, .5 red.

The similarities among the results are remarkable. In every set of data (those of Fechner, of Bleuler and Lehmann, of Flournoy, and of the 35 small studies), the vowel *a* predominately aroused the colors red and blue, *e* and *i* tended to be yellow and white, *o* tended to be red and black, *u* was usually blue, brown, or black, and *ou* (in French) was brown.[2] (Specific phonetic representations of the vowels are taken up below.) As Mudge (1920) noted, "It is probable that the common term 'tone-color' is not a mere figure of speech based upon analogy" (p. 345).

In order to summarize the results more concisely, I converted the data into scores on each of three bipolar dimensions: yellow–blue, red–green, and white–black. These three dimensions are the usual ones for opponent-process theory of color vision (e.g., Hering, 1878; Hurvich & Jameson, 1957), and they may also be used conveniently to describe the coordinates of three-dimensional color space. Not only does the reduction to three dimensions help compress the color data, but it also puts the data into a form that is psychologically meaningful.

The calculations themselves were made simply by subtracting the number of blue responses from the number of yellow responses (or vice versa), of red from green (or green from red), and of white from black (or black from white). Thus, the score on each vowel–color dimension represents a difference between response frequencies.

[2] There is no systematic relation between colors of vowels and the vowels in color names. If there were, we would expect the French *ou* to be red (rouge), *e* to be green (vert), *a* to be white (blanc) or perhaps yellow (jaune), and possibly both *o* and *i* to be black (noir).

Somewhat arbitrary decisions had to be made about how to analyze reports of violet and brown. I decided to divide each violet response into .5 blue and .5 red, even though violet light (wavelengths of 400–440 nm) is usually reported to appear more blue than red (e.g., Boynton & Gordon, 1965). And it turns out that the breakdown into equally weighted blue and red components was a valid decision because this choice tended to diminish the magnitudes of the differences that were finally calculated. Responses of brown were divided into .5 black, .25 red, .25 yellow; that is, brown was treated as dark orange.

Table 2 gives the final results of the tri-dimensional analysis. Needless to say, several objections may be raised to the procedure used and, to a certain extent, the objections may be justified. Nevertheless, the procedure has the great value of reducing the data to a readily manageable quantity and of revealing something about the probabilities of associations between vowels and colors when the colors are organized into a scheme of bipolar dimensions.

The most notable feature of the colors of vowels is the way their brightness varies: *i* and *e* are brightest, *o* and *u* are darkest. Flournoy (1893) noted that this relation was generally true, for he too had analyzed data reported by Fechner (1876) and by Bleuler and Lehmann (1881), as well as his own data. Flournoy proposed as a general principle a "loi de clarté," and Bleuler and Lehmann proposed a "Helligkeitsgesetz." These translate into *law of brightness* and it says that bright-sounding vowels induce bright auxiliary visual sensations. We noted previously the general finding that photisms vary in their brightness as the sounds that produce them vary in their frequency (subjectively, in pitch or brightness). These results for synesthesia produced by vowels (as exemplified by the law of brightness) manifest the generality of the correlation between auditory pitch and visual brightness.

Vowel spectra and vowel colors. The obvious question to ask at this point is, What is the relation between the sound structure of vowels and the secondary visual sensations? Henning (1923) suggested that the differences among colors aroused synesthetically by various speech sounds might be due to phonetic differences among the sounds. Wehofer (1913), and later Masson (1952), pointed to the formant structures of vowels as possible bases for synesthetic vowel colors.

TABLE 2

Synesthetic Colors Induced by Vowel Sounds, Presented as Scores on Three Opponent-Color Dimensions

Vowel	Blue–yellow	Red–green	White–black	N
a	39.62 blue	111.88 red	34.75 black	419
e	54.5 yellow	11.5 green	49.5 white	400
i	47.75 yellow	44.75 red	67.5 white	400
o	44.5 yellow	93.25 red	54.5 black	372
u	36.75 blue	8.0 green	84.0 black	362
u_{French}	18.75 blue	31.0 green	23.5 black	195
u_{German}	14.25 blue	20.25 red	44.25 black	146
ou	0.37 yellow	21.88 red	35.75 black	157

Note. Data derived from Fechner (1876), Bleuler and Lehmann (1881), Flournoy (1892, 1893), and of 35 small-scale studies enumerated in text.

The obvious place to begin a systematic inquiry into the structural basis of the colors of vowels is with the fact that the brightness or pitch of vowels appears to correlate with the brightness of the associated photisms. The vowels *o*, *ou*, and *u* (phonetically, for example, /o/ as in b*oa*t, /u/ as in b*oo*t, /U/ as in b*oo*k) sound relatively low in pitch, as compared to *e* and *i* (e.g., /ɛ/ as in b*e*t or /e/ as in b*ai*t, /I/ as in b*i*t or /i/ as in b*ee*t), which sound relatively high.

Studies of the pitch of vowels trace back at least to the early nineteenth century, when Willis (1830) attempted to produce synthetic vowel sounds. Donders (1857), Helmholtz (1863), and Koenig (1870) tried to determine what the resonance frequencies of the oral cavity are during the production of vowels. Those studies all agreed in demonstrating *u* and *o* to be lowest in frequency, *e* and *i* to be highest. Köhler (1910) was apparently the first to try to match pure tones to vowels. He obtained the following order of increasing frequencies (pitches): *u*, *o*, *a*, *e*, *i*. Köhler's results were later confirmed by Modell and Rich (1915). Vowels are not pure tones, of course, but vowel quality can be mimicked satisfactorily by sounds with spectra that contain two formants. In the case of artificial two-formant vowels, it is the frequency of the

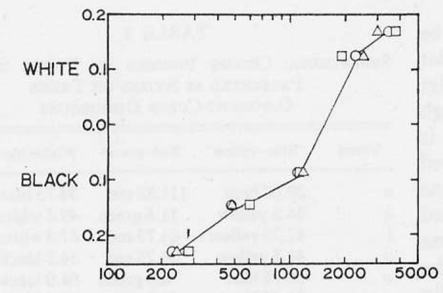

FIGURE 1. Relation of brightness to pitch in visual–auditory synesthesia. (The ordinate shows scores on a dimension of visual brightness, derived from probabilities of synesthetic responses to vowel sounds. The abscissa gives the sound frequencies of the pitch of the vowels as determined by Köhler (1910), circles; Modell and Rich (1915), squares; and Delattre et al. (1952), triangles. The vowels are, in terms of increasing sound frequency, /u/, /o/, /a/, /e/, /i/.)

second formant (F_2) that is most closely related to a vowel's pitch (cf., Delattre, Liberman, Cooper, & Gerstman, 1952).

At this point, it becomes useful to derive, for every vowel, a scale value on each of the three bipolar color dimensions. Because the total number of observations (N) differs from one vowel to another, it is necessary to calculate proportions, that is, to take the ratio of each color score to N. When that is done, values on the white–black dimension come out: a = .084 black; e = .124 white; i = .169 white; o = .147 black; u = .232 black; *ou* = .228 black. The order of increasing vowel-induced brightness is *u–ou*, *o*, *a*, *e*, *i*, the same order that defines increasing vowel pitch. Figure 1 shows how the scale values of vowel-induced brightness plot against the corresponding log sound frequencies obtained by Köhler, Modell and Rich, and Delattre et al. That the relation is almost linear may be fortuitous; nevertheless, the strength of the correlation is impressive and serves to emphasize the close connection between synesthetic color brightness and vowel pitch.

Perhaps the greatest complication to the present analysis is the difficulty involved in deciding on the sound structure of some of the vowels, at least as far as most of the studies on synesthesia are concerned. With regard to the experiments on vowel pitch by Köhler (1910) and Modell and Rich (1915), even though the phonetic forms of the cardinal vowels *a*, *e*, *i*, *o*, and *u* are known (they were the same /a/, /e/, /i/, /o/, and /u/ that were employed in the experiment of Delattre et al., 1952), we cannot always be certain these are the same phonetic forms that apply to vowels described in studies on synesthesia; it is a good guess that they do, but we cannot be absolutely sure.

However, the situation is not desperate. Two of the vowels, *a* and *o*, pose no problem since they are given constant and identical pronunciation, as /a/ and /o/, in French and German, which are the languages that comprise by far the majority of the examples of colored vowels. The other vowels can differ, though, both within and between languages: *u* can be either /y/ or /u/ in French, /u/ or /U/ in German; the vowel *e* can be /e/ or /ε/; and *i* can be /i/ or /I/ in both languages. Fortunately, some of the studies on synesthesia do indicate phonetic forms. Reichard, Jakobson, and Werth (1949) and Masson (1952) stated their vowels in IPA (International Phonetic Alphabet) notation. More significantly, several other studies compared colors induced by alternate pronunciations of the same vowel *e*. Lauret (reported by Suarez de Mendoza, 1890), Suarez de Mendoza (1890), Philippe (1893b), Laignel-Lavastine (1901), Ulrich (1903), Coriat (1913b), and Collins (1929) all described the colors induced by the French vowels è and é (/ε/ and /e/). In every case, both sounds yielded the same colors. Only two studies did not give this result: Baratoux (1887) and Binet and Philippe (1892) each described the colored vowels of a single synesthete. As it turned out, these two reports exactly cancel each other out, for Baratoux's subject said é aroused yellow and è white, whereas Binet and Philippe's subject said é aroused white and è yellow!

Some of the other ambiguities with respect to phonetic form make little or no difference to our interpretations of colored vowels. For instance, the second formants of both /i/ and /I/ are higher in frequency than those of /a/, /ε/, /e/, /o/, /u/, /y/, and /U/. Thus, the overall relation between color brightness and vowel pitch remains basically the same in spite of changes in choice of phonetic forms of vowels. Regardless of the particular phonetic representations of vowels, it is clear that vowel pitch predicts the whiteness or blackness of associated photisms.

With the white–black dimension taken care of, it is now possible to examine whether the two chromatic dimensions of colored vowels are also accountable in terms of their sound spectra. Since the first two formants of vowels appear most crucial to the determination of vowel quality, it is likely that one or both chromatic dimensions of vowel-induced colors depend on the frequencies of F_1 and F_2. Figure 2 plots scale values on the red–green dimension as a function of the ratio of the frequencies of F_1 and F_2. The various vowels have been assigned to the following phonetic categories: /a/, /e/, /i/, and /o/ to *a*, *e*, *i*, and *o* in all languages; /u/ to the French *ou* and to the German *u*; and /y/ to the French *u*. Except for /i/, there is a direct increasing relation between greenness–redness and the ratio F_2/F_1: As the ratio increases, greenness increases and redness decreases.

In this manner we are able to account for a second of the three dimensions of colors as they are linked synesthetically to vowel sounds. The third dimension, yellow–blue, is more difficult to interpret. Simpson, Quinn, and Ausubel (1956) played pure tones to children and asked them to name the hues that the tones conjured up. Yellowness was most often associated with tones of high frequency, blueness with tones of low frequency. Extrapolation of this outcome to the synesthetic colors of vowels would suggest that sound frequency, probably frequency of the second formant, should predict yellowness. Yet we have already seen that sound frequency correlates with whiteness, and in fact, F_2 fails to predict perfectly yellowness of colored vowels, at least when the latter are analyzed in the present way. The failure may be due in some measure to the nature of colored vowels and/or to the present method of analysis.

It is important to bear in mind that the scale values presented here are based only on frequencies of association, not necessarily on strength of association. It is not as though every synesthetic person reported how every vowel varied along each of the three bipolar

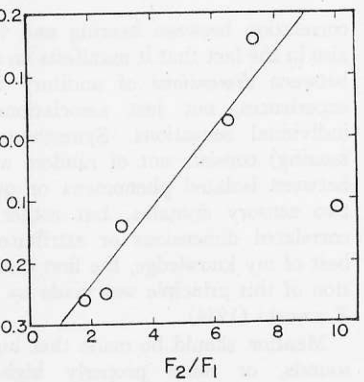

FIGURE 2. Relation of hue to sound structure in visual–auditory synesthesia. (The ordinate shows scores on a dimension of greenness–redness, derived from probabilities of synesthetic responses to vowel sounds. The abscissa gives the ratio of the sound frequencies of the second and first formants of the vowels. The vowels are, in terms of increasing ratio F_2/F_1, /a/, /o/, /u/, /e/, /y/, and /i/.)

dimensions. All that the data show is an overall tendency *across subjects* for correlations to exist between whiteness–blackness and pitch (frequency, presumably of F_2) and between greenness–redness and the ratio F_2/F_1. Note, too, that it was not necessarily the case for any particular synesthete that all the colors of vowels were determined by just one of the dimensional associations. Some vowels might yield colors that express whiteness–blackness; others, colors that express yellowness–blueness; others, colors that express greenness–redness. For example, the vowel *a* might be called red because the dimension of redness–greenness dominated, whereas *i* might be called white because the dimension of whiteness–blackness dominated. If there exists competition between dimensions—for example, if yellowness–blueness and whiteness–blackness both vie for association with pitch (frequency of F_2)—then to the extent that one of the associations is stronger, the other could fail to manifest itself. What this boils down to is the possibility that a strong connection between pitch and brightness might overwhelm a weaker connection between pitch and yellowness. Even so, there was some overall positive correlation between the yellow–blue dimension and F_2: The value of the Spearman rank-order coefficient of correlation between yellow–blue and F_2 was .43. Of course, there always exists the possibility that yellowness–blueness correlates with some parameter whose nature has eluded the present author. The appeal of this possibility is that it implies that there are three crucial dimensions of sound structure, one applicable to each of the three bipolar dimensions of color. In any case, at least two visual dimensions show empirical correlation with sound (formant) frequency of vowels.

Vowel colors and distinctive features. The reader familiar with speech perception may have already noted that the acoustical properties of vowels that are responsible for synesthetically induced colors are also the properties theorized to be responsible for the auditory identification of vowels themselves. The frequency of the second formant and the ratio of the second to first formant are acoustical descriptions of two of the so-called *distinctive features* (Jakobson, Fant, & Halle, 1963).

The distinctive features of speech consist of a set of bipolar dimensions that are presumed to be critical for phonetic identification. One of these features is termed *gravity:* Its two values differentiate high-pitched (acute) from low-pitched (grave) vowels (e.g., /i/ and /e/ versus /o/ and /u/). We might say that gravity as a distinctive feature of vowels correlates with darkness of synesthetically perceived colors.

A second important distinctive feature is termed *diffuseness:* Its two values differentiate compact from diffuse vowels (e.g., /a/ versus /i/). Compact vowels concentrate most of their energy in a small region of the spectrum, whereas diffuse vowels spread energy over larger spectral regions. Hence, given a sound structure containing two formants, a large ratio of F_2 to F_1 implies diffuseness, a small ratio implies compactness. Diffuseness as a distinctive feature of vowels correlates with greenness of synesthetically perceived colors.

Not only do distinctive features provide a logically satisfactory basis for phonetic discrimination, but they appear to have psychological relevance as well. If there do exist a small number of dimensions by means of which all speech sounds are classified, it is small wonder that the same features are responsible for other speech-related phenomena—in the present matter of concern, the synesthetically perceived colors of vowels.

Summary. Analysis of reports on vowel-color synesthesia yield several general principles:

1. Most vowel-color synesthesiae reflect regular correlations between dimensions of visual and auditory experience.
2. The brightness of the induced visual "sensation" is a direct function of the pitch of the vowel (frequency of its second formant). Vowel brightness correlates with the distinctive feature *acuteness.* Acute (high-pitched) vowels yield bright colors; grave (low-pitched) vowels yield dark colors.
3. The greenness and redness of induced colors depend systematically on the ratio of the frequencies of the second to first formants and, thus, on the distinctive feature *compactness.* Compact vowels yield red colors; diffuse vowels yield green colors.

Sound Quality and Perceived Size of Photism

Although the major interest here, and the preponderance of data, concerns the relation between color and sound quality, a significant number of reports on synesthesia also note that the sizes of photisms vary from one sound to another (Anschütz, 1925; Bleuler & Lehmann, 1881; Dudycha & Dudycha, 1935; Karwoski & Odbert, 1938; Riggs & Karwoski, 1934; Vernon, 1930; Voss, 1929; Zigler, 1930). Universally present in those reports was the observation that visual size increased as auditory pitch decreased. High-pitched sounds produce synesthetic visual sensations that are small in size; low-pitched sounds produce synesthetic sensations that are large in size.

Taken at face value, these results imply a second (or perhaps a third) visual correlate to auditory pitch. In addition to visual brightness (whiteness–blackness) and possibly visual yellowness, we also have visual size varying with auditory pitch. There are some additional facts, however, to bear in mind. Just as several studies found that visual brightness depends on loudness as well as increasing pitch—the louder the sound, the brighter the photism (e.g., Pedrono, 1882; Wheeler, 1920; to some extent, Ortmann, 1933)—so too does visual size depend on loudness—the louder the sound, the larger the photism (e.g., Bleuler & Lehmann, 1881; Voss, 1929). The importance of these additional functional relations is made apparent shortly. Meanwhile, let it suffice that induced size is not related solely to pitch, so it may not be pitch per se that is the relevant auditory variable.

Colored Music

Given the penchant these days for multimedia exhibitions—in the arts, in educational technology, to name but two manifestations—one might gain the impression that the association of sound and color in music is a conception of only recent development. In fact, presentation of mixed-mode concerts (patterns of light together with musical sounds) was not uncommon in late nineteenth-century Paris. (Sometimes odors too were included!) The composer Alexander Scriabin, for one, was synesthetic, and some of his compositions were written for and performed in both light and music; by means of polysensory works he hoped to give expression to his mystic world view. An example is Scriabin's (1911) composition "Prometheus," which was written for orchestra, piano, organ, chorus, and color keyboard; it was performed in New York on March 20, 1915. In order to produce it, Carnegie Hall was specially equipped with a color organ; colors were played on a keyboard and projected onto a screen behind the orchestra. The correlation between tone and color was systematic in that C was accompanied by red, D by yellow, E and F-sharp by blues, A by green, and B-flat by gray. For a description of the concert, see Plummer (1915).

Actually, the current vogue for color organs traces back in history at least to the eighteenth century. At that time, a Jesuit named L.-B. Castel proposed (1725) and later built (1735), a color organ on which one could play music that simultaneously expressed itself in color: "For we are born in music, & we have only to open our ears in order to taste it . . . and . . . one has only to open one's eyes in order to taste a Music of colors & to judge it" (Castel, 1735, p. 1621). Castel's color organ was exhibited in 1735. As in Scriabin's compositions, to each note of the scale there corresponded a particular color; furthermore, the associations were, according to the creator Castel, real, not arbitrary: blue was assigned to do, green to re, yellow to mi, and red to sol not by whim but because of some presumably intrinsic appropriateness. The association between blue and do was thought special, for Castel believed blue to be the tonic and fundamental color both of nature and of art. He also believed that the colors formed a harmonic series like that of the notes, a scale of colors, an idea that he may have derived directly or indirectly from Newton (1704; Castel, 1735, 1740). It is certain that his theory derived from Athanasius Kircher's *Musurgia Universalis* of 1650 (Castel, 1725, 1735). Kircher had written of sound as "mimic of light." It is also possible that Castel was influenced by the work of the painter Arcimboldo, who in the sixteenth century conceived a color music (Eastlake, 1840).

A luminous music, played with colored lights that are synchronized to a harpsichord, was proposed again a half-century later by Charles Darwin's grandfather Erasmus Darwin (1790). Like Castel, Darwin suggested that there exist certain natural relations between colors and sounds. By the late nineteenth century and early twentieth century, interest in color organs had blossomed into what might almost be called an epidemic (e.g., Sullivan, 1914).

When it comes to reports on musical synesthesia, we find that the important principles of visual–auditory association that manifest themselves in colored music are basically the same principles that manifest themselves in colored vowels—that is, the relations of visual brightness and size to auditory pitch and loudness. As we shall see, other sorts of associations between light and sound in music tend to be more idiosyncratic. For that reason, consideration of colored music is only cursory.

Colors of musical instruments. First, we may note the associations of colors with the sounds of particular musical instruments (as in Locke's, 1690, and Leibniz's, 1704, references to a blind man understanding what scarlet is by the sound of a trumpet). Reports of colors associated with musical instruments were made by L. Hoffmann, Raff, and Lauret (as cited by Krohn, 1892) and by Bleuler and Lehmann (1881), de Rochas (1885), Lomer (1905), Mudge (1920), Anschütz (1926), and Ortmann (1933). Interestingly, the composer Raff perceived the color of the trumpet's sound as scarlet, and Hoffmann's and Ortmann's subjects reported it as bright red (de Rochas's subject called it yellow, Lomer's subject called it yellow red and Anschütz's two subjects called it blue green and yellow). The painter Kandinsky (1912) described colors of musical instruments, and although the trumpet's color was not included on his list, the tuba was said to arouse red.

It is both easy and difficult to dismiss correspondences between instrument sounds and colors. It is easy to the extent that the correspondences are idiosyncratic, as they often are; and it is difficult to the extent that they are universal, as perhaps some are. Kandinsky (1912) wrote that, musically, the flute resembles bright blueness, "helles Blau." Was he, then, drawing the same analogy as that of the German poet Tieck (1828), who said of the flute "Unser Geist ist himmelblau/Führt dich in die blaue Ferne" (p. 291)?

Mudge's (1920) study is of some importance because it recounts visual responses to music obtained from 42 subjects. Of that number, 34 said that low tones yield dark colors, 26 said medium tones yield medium bright colors, and 36 said high tones yield bright colors. Among the musical instruments, the violin's sound was typically reported to be blue or violet; the trombone's to be dark, usually brown; and the clarinet's and flute's to be bright.

Colors of musical notes. Musical key, musical notes in particular, can also determine the specific colors aroused by music. One can see as well as hear the "Music" of Conrad Aiken (1942):

> The calyx of the oboe breaks,
> silver and soft the flower it makes.
> And next, beyond, the flute-notes seen
> now are white and now are green.

The assignment of specific colors to specific musical notes is quite common, though nowhere near universal, among musical synesthetes. Recall the supposed intrinsic relations described and used by Castel. One of the associations he conjectured to be "natural" was between sol and red. A fascinating, though not quite believable, report by Albertoni (1889) claimed not only that sol is in fact usually called red but, furthermore, that a red-blind subject (what we would now call a protanope) failed also to name correctly the note G (sol). Albertoni named this condition of auditory color blindness *auditory daltonism.* One almost hesitates to bring facts to bear on such a claim, but there are some important points to make. First, the tacit assumption that protanopia consists of a loss of "red sensation" oversimplifies the nature of color blindness. And second, sol (the note G) has been seen (or I should properly say heard) to arouse not just red but also blue (Langfeld, 1914; Ortmann, 1933), yellow (Scriabin, as reported by Vernon, 1930), and white (Starr, 1893). A survey by Gruber (reported by Marinesco, 1912) found 10 respondents who reported coloring musical notes; to sol two of them assigned green, three assigned blue, one red, and one yellow.

An interesting fact is that, as the reports by Langfeld (1914), Ginsberg (1923), Vernon (1930), Dudycha and Dudycha (1935), and Karwoski and Odbert (1938) make clear, the colors associated with music, like the colors associated with vowels, vary along a bright–dark dimension, a psychological dimension that itself correlates with a high–low dimension of sound frequency. Perhaps we should not be too surprised that music and speech sounds are similar in this respect. Slawson (1968) showed that artificial, two-formant sounds are readily interpretable both as vowels and as musical notes and that vowel quality and musical timbre depend in similar ways on the structure of the sound (formant frequencies and spectrum envelope). However, just as there is more to music than the frequency structure of the component sounds, so too is it that sometimes only the more complex features of music suffice to arouse secondary visual sensations.

Colors of musical keys. Vernon (1930) categorized two major types of musical synesthesia besides the three that are already familar to us—the three being (a) brightness and (b) size of photism as functions of sound structure, especially fundamental frequency, and (c) colors proper to musical instruments. Another is the relation between colors and tonalities. Musical composers in particular display such synesthesiae with relatively high occurrence. For instance, Beethoven called the key of B-minor black. The composers Scriabin and Rimsky-Korsakov were both synesthetic, and it has been reported that they agreed on the colors of some musical keys (e.g., that D-major is yellow). I am reminded, in this regard, of E. T. A. Hoffmann's (1810/1899):

> auch hatte ich gerade ein Kleid an, das ich ernst im höchsten Unmut über ein misslungenes Trio gekauft, und dessen Farbe in Cis-Moll geht, weshalb ich zu einiger Beruhigung der Beschauer einen Kragen aus E-dur-Farbe daraufsetzen lassen. (p. 61)

Colors of musical patterns. Interestingly, music may be reported as colored according to the individual composer. Raines (1909) described the several synesthesiae of a young woman. Included was the observation that she found works of Chopin to be purple, of Mozart to be green, and of Wagner to be red. Colors specific to composers were also described by Anschütz (1926) for one of his three synesthetic subjects.

Vernon (1930) and Anschütz (1926) pointed out that synesthesiae can be based on other musical patterns, particularly on complex temporal patterns such as progressions, styles, and so forth. It is not surprising then that individual compositions may evoke specific synesthetic reactions. Schumann (in Erler, 1887) was reported to have assigned special colors to specific musical works. A similar conclusion was reached by Karwoski and Odbert (1938). They found that synesthetic responses often depended on musical patterns, at least in the relatively simple musical materials (e.g., "Jingle Bells") that were studied.

Just as the important dimensions of the auditory stimulus that are responsible for musical synesthesiae can be quite complex, so too can be the synesthetic responses themselves (Karwoski & Odbert, 1938). Visual sensations aroused by music need not be limited or confined to simple spots of color. Often the entire visual field fills with colors that change over time with the music; some subjects report several colors simultaneously, each color reflecting a particular aspect of the music. The shapes of the photisms also vary, particularly with musical tempo; the faster the music, the sharper and more angular the photism.

An important study was conducted by Karwoski, Odbert, and Osgood (1942), who applied verbal tests of bipolar opposites (like the semantic differential that Osgood, Suci, and Tannenbaum, 1957, developed later) to nonsynesthetic subjects. Verbal reports concerning relations of color and form to music were similar to responses to music that are obtained from synesthetic subjects.

Can Sounds Produce Visual Sensations?

Several of the small-scale reports that yielded part of the data in Table 2 appear to provide examples of what we may call strong synesthesia. Typically, the subjects of those studies claimed that sounds produced visual sensations. The same appears to be true of the many cases described by Bleuler and Lehmann (1881). On the other hand, the report of Flournoy (1892, 1893) was based on responses to a questionnaire. Without careful examination of subjects, it is difficult to know whether many or even most of the examples might have consisted of relatively weak associations between color and sound.

In any event, it is probably difficult to prove in any given circumstance that strong rather than weak synesthesia is evident. For it is not clear just how one would go about discovering whether a stimulus appropriate to one modality (say a sound) actually produces a sensation appropriate to another (such as a color), though classical conditioning of sensations does appear to be possible (Leuba, 1940). Sometimes synesthetic subjects report the associated visual sensation to appear not in visual space but rather in the sound itself. A relevant datum is the observation by Ortmann (1933), on a synesthetic young woman, that there was no interaction between synesthetically induced color and color produced simultaneously by a visual stimulus except when the colors were the same. Under that condition, synesthetic color and real color fused!

Perhaps it is more appropriate to speak of synesthetically induced "images" than of synesthetically induced sensations. Colors induced by sounds are usually quite distinguishable from colors induced by light. Synesthetic images are secondary and contingent; often they appear with some delay after the onset of primary sensations. This is not to say that synesthetic images do not have many of the properties of sensations nor that they are never as strong or vivid. Imagery can strongly resemble perception, as several experiments have demonstrated. In Perky's (1910) well-known study, very weak visual percepts of objects such as a tomato and a banana were often interpreted as visual images, from which result Perky deduced that "the materials of imagination are closely akin to those of perception" (p. 451). Perky's result was later confirmed by Segal and Nathan (1964). In a study that employed analytical tools of the theory of signal detectability, Segal and Fusella (1970) found that imagery interferes with sensory detection, particularly when the test stimuli were presented in the same modality as the images.

To some extent, then, dimensions or attributes of images overlap dimensions or attributes of sensations. As Paivio (1971) concluded, "imagery and perception are continuous modes of experience" (p. 144). It might be convenient to think of the conjunction of imagery and sensation in terms of some common portion of the neural system that both actuate. Ortmann (1933) argued that

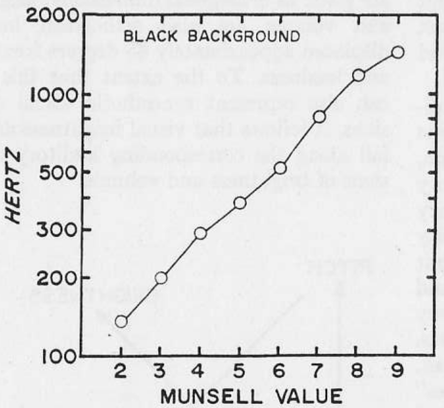

FIGURE 3. Matching of auditory pitch and visual brightness by nonsynesthetic subjects. (Average settings of sound frequency (loudness held constant) to gray surfaces that varied in luminous reflectance from 3% to 80%. From "On Associations of Light and Sound: The Mediation of Brightness, Pitch, and Loudness" by Lawrence E. Marks, *American Journal of Psychology*, 1974, 87, 173–188. Copyright 1974 by University of Illinois Press. Reprinted by permission.

the colored hearing of his subject was not imagery but rather sensation. If imagery and sensation lie on a continuum, it may be unnecessary to make Ortmann's distinction.

Status of Visual–Auditory Synesthesia

An important issue to consider now is the status of the synesthetic correspondences between auditory and visual sensations. One approach is to treat synesthesia as a special phenomenon distinctive in its own right. This approach is based on the supposition that in synesthesia, sounds truly arouse sensations of color and that such a condition is not normal.

Of course, it may not be possible to decide whether sounds can actually yield visual sensations. But even if they do, there exists an alternative approach whereby synesthesia is regarded not so much as a distinct, nonnormal entity but as the end point of a continuum on which sensory correspondences vary in strength. Much of the evidence on colored hearing tends to support the latter approach in that synesthetic relations appear to express correspondences between dimensions of sensory experience that are fundamental to sensation in general. Given the marked similarity among results obtained in the studies just reviewed, the generality of at least some of the visual–auditory correlations can hardly be denied. The correlations between vowel quality and color are similar with native speakers of French and German, and Reichard et al. (1949) argued that they are similar in German, Czech, Serbian, and Russian.

The second half of the argument is that correspondences between light and sound that are general to synesthetes are also general to nonsynesthetes. Results reported by Karwoski et al. (1942) imply equivalent responses to music by both synesthetic and nonsynesthetic subjects. Wicker (1968) obtained similarity judgments and semantic judgments of colors and tones from nonsynesthetic subjects; his results indicated a correlation between visual brightness and auditory pitch. Recently, I (Marks, 1974) asked nonsynesthetic subjects to search for tones that matched gray surfaces. The results showed general agreement that increasing auditory pitch goes with increasing surface brightness, as can be seen in the averaged data plotted in Figure 3. Most subjects also aligned increasing loudness with increasing brightness, but others did the reverse, aligning loudness with darkness.

There are two additional lines of evidence to support the contention that synesthetes translate sensations from one modality to another in basically the same way that nonsynesthetes do and that these translations reflect fundamental properties of sensation and cognition. These lines of evidence comprise synesthesia under drugs and phonetic symbolism.

Synesthesia under drugs. Mescaline and hashish often produce strong synesthetic experiences in normal (nonsynesthetic) subjects, as has been noted time and again over the past century. The French poet Théophile Gautier (1843) described how he would hear colors when he was under the influence of hashish:

> mon ouïe s'était prodigieusement développée; j'entendais le bruit des couleurs. Des sons verts, rouges, bleus, jaunes, m'arrivaient par ondes parfaitement distinctes. Un verre renversé, un craquement de fauteuil, un mot prononcé tout bas, vibraient et retentissaient en moi comme des roulements de tonnerre. Chaque objet effleuré rendait une note d'harmonica ou de harpe éolienne. (1846, p. 530)

And he described his response to piano music, "Les sons en jaillissaient bleus et rouges."

Charles Baudelaire (1860/1923), no slacker in the hashish department, wrote similarly of its effect on sensation, namely, how "L'odorat, la vue, l'ouïe, le toucher participent également," and, "Les sons se revêtent de couleurs, et les couleurs contiennent une musique." Interestingly and importantly, Baudelaire followed these statements with a dialogue between author and reader, in which the reader commented that the synesthetic correspondences are not unique to hashish but appear also in the nondrugged state (i.e., to the poet); to this comment the author, Baudelaire, responded in turn that hashish has, of course, no supernatural effect. What it does is to make more vivid those correspondences that exist in the normal state:

> Les sons se revêtent de couleurs, et les couleurs contiennent une musique. Cela, dira-t-on, n'a rien que de fort naturel, et tout cerveau poétique, dans son état sain et normal, conçoit facilement ces analogies. (p. 218)

The vividness of synesthesia provoked by hashish is also apparent in Ludlow's (1857) account:

> Thus the hasheesh-eater knows what it is to be burned by *salt* fire, to *smell* colors, to *see* sounds, and, much more frequently, to *see* feelings. How often do I remember vibrating in the air over a floor bristling with red-hot needles, and, although I never supposed I came in contact with them, *feeling* the sensation of their frightful pungency through *sight* as distinctly as if they were entering my heart. (pp. 149–150)

Both Gautier and Baudelaire emphasized the correspondences between sounds and colors that manifested themselves under hashish intoxication. Cairns (1929) described the visual images that music aroused in him after he was injected with peyote extract (mescaline). Delay, Gérard, and Racamier (1951) noted that auditory–visual synesthesia is found under mescaline intoxication, and Beringer (reported by Werner, 1940) found that mescaline produces experiences of colored hearing in which visual brightness correlated with auditory pitch. It would appear then that there is an especially intimate connection between vision and hearing, at least to the extent that the auditory–visual forms dominate both normal and drugged synesthesiae and, furthermore, that synesthesiae induced by drugs consist predominantly, if not exclusively, of enhancements of normal cross-modal interrelations.

Synesthesia and phonetic symbolism. Some of the strongest evidence to support the view that visual–auditory correspondences found in synesthetes are similar or identical in nature to correspondences found in normal persons (nonsynesthetes) adduces from studies of sound symbolism in speech—what is often termed *phonetic symbolism.* The notion that the sounds of words convey meaning has a history that goes back at least to Plato (*Cratylus*) and was echoed, in one form or another, by Rousseau (1753/1839) and later by Balzac (1832/1961) who asked, rhetorically, "Are not most words colored with the idea that they represent externally?" (p. 507). Werner (1940) called the intrinsic meaning of sounds an example of the *physiognomic* aspect of language—language is not just an abstract, formal system of symbols. To some extent, words "belong to" objects.

Sapir (1929) was among the first to verify experimentally that vowel sounds differ with respect to the sizes of the objects they suggest. For instance, objects named with nonsense syllables containing the sound /a/ appear larger than objects named with syllables containing /i/; this is true of children as well as of adults and of native speakers of Chinese as well as of native speakers of English. Since Sapir's report, many studies have been carried out with the aim of discovering whether different speech sounds bear some intrinsic, connotative relation to the objects their words represent.

Newman (1933) constructed pairs of nonsense syllables that contained different vowel sounds and asked subjects both which syllable of each pair seemed larger and also which syllable seemed brighter. From large to small the order of the vowels was /o/, /a/, /æ/, /ɛ/, /e/, and /i/; from dark to bright the order was /u/, /a/, /æ/, /e/, /ai/, /I/, and /i/. First of all, we note that the two orders correlate highly with one another. Second, we note that both orders also correlate strongly with pitch of the vowel (i.e., with frequency of the second formant). The relations between vowel sound and the dimensions of size and brightness obtained in Newman's experiment on phonetic symbolism are the same as the relations manifested in colored hearing. In the African language Ewe, high-pitched words describe small objects, low-pitched words describe large objects (Kainz, 1943). Studies on phonetic symbolism by Czurda (1953) and on onomatopoeia by Wissemann (1954) support Sapir's and Newman's results. Czurda found /a/, /o/, and /u/ to be large vowels and /ɛ/ and /I/ to be small vowels; Wissemann found /u/ and /o/ to be dark and /i/ to be bright. Of theoretical importance is the finding that phonetic symbolism is absent in deaf people who have learned to talk (Johnson, Suzuki, & Olds, 1964). Thus, the cues to phonetic symbolism appear to be in sounds, not in kinesthesis of speech production. This interpretation is supported by the study of Bentley and Varon (1933), who verified Sapir's and Newman's findings and then went on to make an important additional observation, namely, that the sounds *themselves* vary in size and brightness. Not only do sounds *imply* differences in brightness and size, but they *can be* more or less large, more or less bright.

These experiments on phonetic symbolism were conducted, presumably, with nonsynesthetic subjects. The simplest hypothesis, then, is that sounds, such as vowels, differ among themselves with regard to the dimensions of brightness and size and that in synesthesia, the visual images (photisms) that are aroused by the sounds correspond in their brightness and size to the brightness and size of the (vowel) sounds.

It is worthwhile, in this regard, to note and modify Brown's (1958) caution against equating phonetic symbolism with synesthesia. His reason was that the results of experiments on phonetic symbolism tend to produce a body of results that is stable and consistent from person to person, whereas results on synesthesia show large individual differences. Although it is true that individual differences in synesthesia are sizable, there exist several common, underlying currents that are consistent from synesthete to synesthete; furthermore, at least some of the common principles governing synesthesia are similar to those governing phonetic symbolism.

What Dimensions Correspond in Visual–Auditory Synesthesia?

After cutting through the idiosyncratic differences among synesthetes, we find several general principles underlying auditory–visual correspondences in synesthesia. First, low-pitched sounds arouse dark photisms, high-pitched sounds arouse bright ones. Second, low-pitched sounds arouse spatially large photisms, high-pitched sounds arouse smaller ones. At first glance, it would appear that we have a single auditory dimension, namely pitch, which maps itself onto two visual dimensions, namely brightness and size. This interpretation is in line with a conclusion of Karwoski et al. (1942). They proposed as the fifth of a set of general principles of colored music, the "principle of alternate visual polarities and gradients," which states that more than one visual dimension may parallel a single auditory dimension.

There are some additional facts, which were mentioned earlier, that bear on this interpretation. First, louder sounds arouse brighter photisms than do softer sounds; and second, louder sounds arouse larger photisms than do softer sounds. If we were to extrapolate the logic just employed, we would have to conclude also that a second auditory dimension, namely loudness, maps onto the same two visual dimensions of brightness and size.

There exists an alternative interpretation. Note that psychophysical studies of hearing show that even simple sounds vary along at least four different psychological dimensions. Besides pitch and loudness, sounds are often described as more or less *voluminous* and more or less *dense*. Low-pitched loud sounds are large; high-pitched loud sounds are dense. Thus pitch, loudness, volume, and density all depend in different ways on sound frequency and intensity.

Early in the twentieth century several references were published to yet another dimension of auditory experience, brightness. Hartshorne (1934), Hornbostel (1931), Rich (1919), and others identified brightness with pitch; and Hartshorne and Hornbostel argued for the analogy (if not the identity) of auditory and visual brightness. However, other evidence was brought to bear that suggested brightness is not merely pitch; for one, brightness also depends on sound complexity (Abraham, 1920). Troland (1930) argued that brightness increases not only with increasing pitch, but also with increasing loudness; and most importantly, Boring and Stevens (1936) found brightness to be the same as density.

Recent work involving the scaling of auditory density by magnitude estimation (Guirao & Stevens, 1964; Stevens, Guirao, & Slawson, 1965) demonstrates the way that auditory density increases both with sound frequency and sound intensity. If brightness and density are one and the same attribute of sounds, but different from pitch, then Hartshorne and Hornbostel are partially correct. Auditory brightness does correspond to visual brightness, at least in colored-hearing synesthesia. (Recall, as was described earlier, the "law of brightness" proposed by Bleuler and Lehmann, 1881, and by Flournoy, 1893). However, brightness is not the same as pitch. Brightness increases markedly with increases in sound frequency, and at a given constant level of loudness, brightness correlates closely with pitch. But brightness increases also with loudness; pitch may do so too at times, but not always and not in the same way. If sound frequency is held constant and low, pitch increases as intensity increases; but if sound frequency is held constant and high, pitch decreases as intensity increases (Stevens, 1935). Increasing the complexity of sound decreases auditory brightness (Abraham, 1920), and increasing sound complexity also decreases synesthetically induced visual brightness (Riggs & Karwoski, 1934).

A similar argument can be made with respect to auditory volume and visual size. Auditory volume increases as frequency decreases (and, concomitantly, as pitch decreases), but it increases as intensity increases (and, therefore, as loudness increases) (Terrace & Stevens, 1962). Synesthetically induced visual size follows the same pattern. Thus, it appears that the size of photisms in auditory–visual synesthesia corresponds to, or at least correlates with, the size (volume) of the sound. Like brightness, volume does bear a relation to pitch, but it is not auditory pitch proper that determines visual size, just as it is not pitch proper that determines visual brightness.

These interrelations are depicted in Figure 4, which is a schematic representation of two-dimensional auditory space. Pitch and loudness are given as orthogonal dimensions; brightness and volume are also orthogonal but are displaced approximately 45 degrees from pitch and loudness. To the extent that this space can also represent synesthetic visual dimensions, it follows that visual brightness and size fall along the corresponding auditory dimensions of brightness and volume.

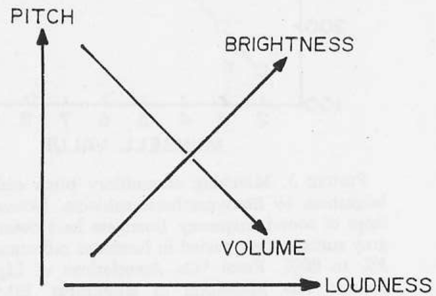

FIGURE 4. Schematic representation of the psychological space for simple sounds.

The present interpretation is diametrically opposed to the initial one. Instead of visual brightness and size both corresponding to auditory pitch, neither corresponds to pitch. Brightness parallels brightness and size parallels size. It seems fair to venture that the same basic correlations arise both in synesthetes and in nonsynesthetes and that these two correlations are therefore fundamental to the normal sensory and conceptual systems of humans.

Summary

It does not matter whether one considers perception by synesthetes or by nonsynesthetes; in both cases the correlations between dimensions of visual and auditory experience are nearly identical. These dimensional, cross-modal correlations express themselves most vividly in people not normally synesthetic by means of hashish and mescaline intoxication. The same correlations express themselves in the nondrugged states, less vividly to be sure, in the way that sounds of speech as such can convey particular meanings (phonetic symbolism). Interpreting the correlations of visual and auditory experience in terms of known dimensions of sensory experience, it seems that there exist two outstanding, universal, cross-modal relations: one between auditory brightness or density and visual brightness, the other between auditory volume and visual size.

What is Synesthesia All About?

There has perhaps been as much written about *why* synesthesia is as about *what* it is. In their impact and significance, theories of synesthesia vary from predictable to unpredictable, from cogent to absurd. Mahling (1926) and Ortmann (1933) reviewed at length many of the early theories, and the interested reader may wish to consult those works. The present exposition deals only with some of the more interesting and important hypotheses.

All theories of synesthesia are theories of mediation. Sensations or sensory dimensions linked to one another must be linked by something. We may call that link a learned association—a psychological entity, perhaps with overtones of neural basis. We may call the link a physiological response—a neural, muscular, or other physiological entity of actual or mythological status. Or by response we may mean some tidbit of behavior, again either actual and measurable or covert and mythical. Finally, we may call the link cognitive, by which we mean none of the above or perhaps all of them. To say the link is cognitive, empty though that statement may seem, is foremost to propose that the plane of explanation should be psychological. Moreover, to say that the link is cognitive implies that synesthesia is involved in thought, in knowledge, in the way that the world is *represented* in consciousness.

Synesthesia as Learned Associations

As might be expected, several investigators (Calkins, 1893; Claparède, 1903; Dresslar, 1903; Harris, 1908; Laignel-Lavastine, 1901; Langenbeck, 1913) postulated that synesthesia is the outcome of experienced conjunctions between stimuli encountered early in life. Harris qualified his opinion by theorizing that the tendency to be synesthetic is strongly determined by genetic factors, but he believed that the actual associations are themselves totally the result of chance contiguities. In a few instances no doubt this view is correct, as, for example, in the synesthesia described by English (1923). He reported the colored music of a 3-year-and-11-month-old boy: Soft music was yellow, loud music was black. The basis for the correspondences was, according to the child, that yellow crayon cannot readily be seen on a wall, whereas black can, just as soft music may not easily be heard, but loud music can. Whether associations like these can explain any sizable proportion of synesthesiae, if in fact they even *explain* this one, is a question that may be impossible to answer. Nevertheless, the existence of even a single case of synesthesia based on experienced conjunctions would serve to make associative learning a factor to consider.

Certainly to the extent that experienced conjunctions are assumed to be *fortuitous*, it is difficult to see how they can lead to the regularities that are observed in synesthesia, particularly those in colored hearing. The visual brightnesses and hues associated with vowel sounds cannot easily be explained in such a manner. It is curious that Colman (1894) gave such an interpretation to the data on auditory–visual synesthesia he compiled, particularly since he noted that the colors produced by vowel sounds showed less variation from subject to subject than did the colors produced by written letters of the alphabet.

Of course, one might attempt to adhere to the associative theory but endeavor to account for the observed regularities by hypothesizing some universal experience as the basis for the associations. That is, as most youngsters grow up they may encounter the same conjunctions of visual and auditory stimuli and sensations in their environments. This appears to be the view that Binet (1892, 1893) hinted at. Although Binet argued for an associative basis to synesthesia, he was aware of the regularities that govern connections between color and sound.

If the associative hypothesis is to be taken seriously, then some attempt should be made to find the source of the common conjunctions between dimensions of different modalities. With respect to colored vowels, one possible explanation that comes to mind is that children's books often present letters and words in colors. Thus, by the association of sound with the printed letter, printed letter with its color, children may tend to associate sounds with colors. This very explanation was actually propounded to account for the vowel colors that Rimbaud expressed in his "Le Sonnet des Voyelles" (see Starkie, 1961).

But regardless of the correctness of its application to Rimbaud's invention, it would seem difficult to maintain this explanation for colored vowels in general. First of all, if the sequence of events given above were correct, we would expect the association between color and written letter to be much stronger than the association between color and sound, since the former association would be more direct. Yet the reverse is actually true. It is vowel sounds that are potent as synesthetic stimuli. Second, in order to explain the great (i.e., cross-linguistic) generality of vowel brightness and darkness, we would have to postulate that the same vowels are connected with bright and dark colors in children's books printed in English, German, French, and perhaps several other languages as well. The only way to account for such a remarkable cross-linguistic occurrence would be in terms of some other, more general, basis to the linking of sound and color, in which case the explanation in terms of colors in alphabet books itself becomes secondary if not superfluous.

If there is any truth to the theory just described, there may now be ample opportunity for experimental verification, for one of the recently developed means to teach reading to children is called "Words in Color" (Gattegno, 1962). Every letter of the alphabet (actually every sound) is represented by a different color, 39 in all. Thus, there now exists a sizable number of primary grade students who are exposed on a regular basis to similar correlations of sound and color.

Before taking leave of the hypothesis that synesthesia is learned, we may ask a closely related question, namely, Can synesthesia be learned? Binet (1893) artificially paired colors and sounds, which he proceeded to teach to himself. His proficiency at naming the colors in response to the sound stimuli became great—equal to that of a synesthete. Binet took this result as some evidence in favor of his suspicion that synesthesia is learned, based on contiguities encountered in childhood.

Subsequent experimentation has failed to shed much more light on the role of learning in the development of synesthesia. Several experiments investigated the capacities of adults to associate colors with sounds. In the first (Kelly, 1934), 18 subjects were given eight pairs of colors and sounds (notes from the tonic C scale played on an accordian). With repeated presentations some learning occurred, but there was no tendency for the subjects actually to "see" the colors when the notes were played.

In a second experiment (Howells, 1944), eight subjects heard an organ note, which was followed by a color (red or its blue-green complement). During training the colors were presented at maximal saturation, but during subsequent testing the saturations were reduced. Furthermore, on some trials during the test period the complementary color was presented instead of the primary one that had been used throughout training. That is, note C might be paired with red during training and, usually, also in testing; but occasional test trails would consist of C followed by blue green. The experimental question was, Will the prior pairing of C and red lead the subject to see red instead of blue green on those trials? Howells did find a positive effect. However, whether the organ notes actually influenced the color perceptions is moot. The training period might have led only to the development of particular verbal response tendencies, either direct or mediated.

A study reported by Ellson (1941b) suggests that the conditioning of sensation is possible. Ellson repeatedly paired a 1000-Hz tone with a white light, and he found that "auditory hallucinations" developed. Sometimes, these light-invoked sensations of sound could not be distinguished from sensations produced by auditory stimuli. Furthermore, conditioned auditory sensations appeared quite resistant to extinction (Ellson, 1941a). Similar results were obtained by Leuba (1940) and by Leuba and Dunlap (1951). In these experiments, the conditioning sessions were conducted while the subjects were under hypnosis. Test sessions were conducted after hypnosis, but the conditioning sessions were not remembered. (The subjects were told, under hypnosis, not to recall the conditioning.) Sensations of touch and smell, conditioned to sound, came on automatically and involuntarily, and again on several occasions the conditioned sensations could be mistaken for primary sensations.

Despite the positive results, one might reasonably argue that none of the attempts to induce experimental synesthesia has any relevance to the question of the ontogeny of synesthesia as it actually or normally takes place. For one thing, synesthesia usually begins in childhood. Thus, even if regularly experienced conjunctions of particular lights and sounds are important to the development of auditory–visual synesthesia, there is always a possibility that the formation of associations will proceed differently in children than in adults. For another thing, the consistent relations that are observed in synesthesia require either that the same types of visual and auditory stimuli actually appear with greater-than-chance regularity in different parts of the world or, alternately, that people are somehow intrinsically tuned or programmed to develop certain associations more readily than to develop others. Under this last interpretation, one could hardly expect stimuli that were paired artificially to yield the same sort of affiliation as that which would derive from stimuli that were "properly" paired.

There is a final point concerning the role of experienced contiguity. We may take a moment to consider the relation between sound sensation and induced visual size. As has been mentioned several times, sounds vary along the attribute of volume: High-intensity, low-frequency sounds appear to be large; low-intensity, high-frequency sounds appear to be small. Similarly, size of visual photism in synesthesia follows auditory volume. Now, it might be that the perceived sizes or volumes of sounds are themselves learned characteristics, in which case the synesthetic relations, to the extent they follow directly, would also have an experiential basis. The rationale behind attributing the auditory dimension of volume to learning is that, as the laws of physics tell us, large objects tend to produce lower sound frequencies (when set into resonant motion, for instance) than do smaller objects. The frequency range of a piccolo is displaced well above that of a bassoon. Large objects thud when they fall or are stricken, small objects ping and tinkle.[3] Such an argument was used by Osgood et al. (1957) to explain synesthesia and metaphor, and a similar explanation was presented by Brown (1958) to explain phonetic symbolism.

There is one item of evidence to suggest that experienced conjunctions of visual and auditory stimulation are not necessary to the perception of correspondence between visual size and auditory volume. Stevens (1934) found that a congenitally blind woman responded essentially the way sighted subjects do with respect to auditory volume, once the existence of this attribute was pointed out to her. If this is correct, then it would suggest that experience of simultaneous visual and auditory stimulation is not necessary for the appreciation of volumic differences among sounds. Of course, physical differences in size among objects can be comprehended by other means (e.g., touch and verbal description) and

[3] I assume the sound symbolism in the last sentence was not lost to the reader.

thereby perhaps provide a basis for associative learning.

Of some relevance in this context is an observation made by von Békésy (1959) to the effect that the sensation produced by a vibrator resting on the skin feels smaller the higher the vibratory pitch (the higher the stimulus frequency). Thus, psychophysical responses of the vibration sense of the skin parallel psychophysical responses of the vibration sense of the ear. It is difficult to see how an association theory could account for the dependence of perceived vibratory size on vibration frequency.[4]

Synesthesia as Neural Short Circuit

A theory described by Clavière (1898) states that synesthesia is pathological. Perhaps. And perhaps we all are crazy. One version of this theory attempts to account for synesthesia in terms of the cross-excitation of sensory centers in the brain. Pedrono (1882) and de Rochas (1885) proposed such a physiological theory. In essence, it implies either some sort of neural short circuit or else an anastomosing of neurons from two or more senses. A first cousin to this theory is Coriat's (1913a) hypothesis of incomplete physiological differentiation. Basically, all of these theories postulate some abnormal condition; thus, this type of theory is really a variant of the view that synesthesia is pathological. But the generality of so very many synesthetic correspondences tends to diminish the value of the theory, since apparently it would have to apply as well to nonsynesthetes. (Unless we wish to adhere to the aforestated view that insanity prevails.) Of course, to the extent that one believes that all psychological phenomena have direct physiological correlates, some type of physiological theory must be correct. But there is no guarantee that a physiological theory will be useful in elucidating psychological mechanisms.

[4] One explanation might be that low-frequency vibrations actually spread out over larger areas of skin. Though this is possible, note that measurements of lateral spread (Sherrick, 1953) show a nonmonotonic effect of increasing vibratory frequency.

The Mediation of Synesthetic Correspondences

The theory described by Clavière that is of greatest potential is the theory of equivalent excitation. It was propounded by Féré (1892), Bleuler and Lehmann (1881), and Flournoy (1893). In essence, the theory proposes that synesthetic correspondences derive ultimately from the existence of common properties of responses to sensory stimulation. Féré's view was that stimuli that impinge on all of the senses produce general physiological reactions, such as changes in muscular tonicity, and that these physiological responses act as mediators in the development of synesthesia. When two stimuli excite different senses, but produce physiological responses that have some common properties, those stimuli will tend to be associated; the greater the degree of commonality in response, the more closely associated in synesthesia the stimuli will be.

The views of Bleuler and Lehmann and of Flournoy were that the common responses are emotional (i.e., that the linkage between sensations in synesthesia derives from commonality of affect). Frequently, sensations linked synesthetically do appear to show an affective basis, as Calkins (1895), Whipple (1900), Riggs and Karwoski (1934), and Odbert, Karwoski, and Eckerson (1942) noted. As early as the eighteenth century, Herder (1772) wrote of an affective synesthetic bond among various senses. In *Abhandlung über den Ursprung der Sprache*, in which he proposed an onomatopoetic theory of the origin of language, Herder argued that sound and color interrelate via feeling.

A more recent version of Féré's theory is that of Börnstein (1936, 1970), who also argued that sensory stimulation has a general effect on muscular tonicity. Börnstein claimed that this generalized tonic response serves to unite the senses. The most important manifestation of the unity of the senses is, according to Börnstein, the general sensory attribute of brightness, which he stated is correlated with heightening of muscular tone, regardless of the particular sense modality that is aroused. In a similar vein are Vernon's (1930) hypothesis that musical synesthesia relates to a primitive autonomic response and, even more closely, Werner and Wapner's (1949) sensori-tonic field theory, which is based on empirical evidence that muscular tone and perceived body orientation can be influenced by stimulation of several modalities.

Be these as they may, the wide variety of sensory correspondences that appear in synesthesia (the number of different corresponding pairs of dimensions found in various synesthetes) would hardly seem accountable solely in terms of anything as universal and general as body tonus. A similar conclusion may be reached about emotion or affect. Downey (1911), for example, rejected affect as a general basis for the visual–gustatory synesthesiae that she described. Affect (emotion), like tonus, appears to be too narrow a basis to account by itself for all of synesthesia.

A Theory of Synesthesia

But even though the simple hypotheses just described are deemed insufficient to account adequately for synesthesia in all of its sundry forms, the general approach seems correct; and, furthermore, the specific proposals just examined (that synesthesia emerges from certain common tonic and affective responses to stimulation) may turn out to provide at least part of an adequate theory. To repeat the general hypothesis, synesthesia derives from responses common to stimulation of all sense modalities. A little thought on the matter leads us to consider the possibility that the two common responses already considered (tonus and affect) are manifestations of the general factors of connotative meaning that Osgood et al. (1957) derived by means of semantic differentiation. Osgood et al. discovered that three factors are of wide applicability to the meanings of concepts; they even noted that the use of bipolar dimensions for semantic evaluation itself derived from the bipolarity of dimensions obtained in the study of synesthesia. Thus, it is not at all surprising that we come full circle and invoke those same factors of connotative meaning in a theory of synesthesia. (I shall continue to employ the term *connotative meaning* even though Osgood later (e.g., 1969, 1971) used the term *affective meaning*. In the present usage, *affect* has a more restricted meaning, closer to the single dimension of pleasantness–unpleasantness.)

The three bipolar factors derived from semantic differentiation of concepts are called *evaluation*, *potency*, and *activity*. The dimension of evaluation includes an affective component, so to the extent that affect provides a cross-modal link in synesthesia, it may be subsumed under this first factor. Unfortunately, no other one-to-one correlation reveals itself. Tonus, for instance, cannot very easily be ascribed either to the factor of activity or that of potency, though it contains characteristics of both. More to the point, it does not appear that we can apply to synesthesia in any simple, one-to-one manner the three factors obtained from semantic differentiation—no more than we were able to apply affect and tonus in that way, two possible dimensions of equivalent excitation. We cannot say, for example, that visual brightness correlates with auditory pitch because both reflect a single, underlying cognitive dimension like evaluation. They may also reflect activity. Every pair of synesthetically correlated sensory dimensions probably partakes to various extents of several underlying cognitive dimensions or factors.

Perhaps the solution to the problem lies merely in how the pie gets divided. It might be that some different set of factors besides evaluation, potency, and activity could provide a more direct, one-to-one correspondence with underlying synesthetic dimensions. But just as likely, or even more likely, the synesthetic dimensions are actually complexes that themselves vary along several component dimensions, just as sensations of sound and light vary with respect to several psychological attributes or dimensions.

It is useful in this context to look at the way Osgood (1971) interpreted the three factors of connotative meaning. According to his theory, meaning consists of a process of mediation, whose connotative components correspond to the dimensions that obtain via semantic differentiation. The mediation processes themselves are treated as learned representations of responses that become attached to their signs through learning (i.e., via differential reinforcement). More importantly to our present concern, the representational components are not simple responses but complexes derived from several reaction systems. For our purposes, we might interpret

these systems to include affect (as that term is used in the present article), muscular tonic reactions, and so forth. Viewed in this manner, the present theory agrees in several fundamental respects with Osgood's, particularly as to the multidimensional mediation of synesthesia. A major difference, however, is that the present theory suggests that several of the dimensions of intersensory correspondence derive not from learning based on common and regular features of the environment but from the basic structure of people's sensory and nervous systems.

We may attribute synesthesia to some sort of fundamental processes or functions, perhaps those with their own special neural loci, at which stimulation of different sense organs produces common effects. This is in some manner equivalent to saying that synesthesia derives from what Aristotle called the *common sense* (e.g., *De anima*, 442b). Much the same point was made by Werner (1934), who argued that sensory stimulation first arouses a common, synesthetic sense before differentiating into specific, modal perception. The response at the first level is presumably more diffuse and malleable.

An interesting and important study was conducted by Osgood (1960) on the cross-cultural generality of synesthetic thought. Verbal concepts such as good, bad, white, and black were evaluated on visual scales such as light–dark, large–small, and up–down by Anglo-Americans, Navajos, Mexican-Spanish, and Japanese. Not only were the verbal–visual synesthetic tendencies much the same for members of each cultural and linguistic group, but there were good correlations between groups as well. For instance, Anglos, Navajos, and Japanese all agreed that *white* is *thin* and *calm*; that *fast* is *thin*, *bright*, and *diffuse*; that *heavy* is *down*, *thick*, *dark*, and *near*. Because of their cross-linguistic generality, Osgood interpreted his results as casting doubt on the importance of Whorf's (1956) hypothesis that cognition (meaning) is tied to and dependent on linguistic structure. Instead, the generality must mean that universal experiences are more important and/or that innate determinants are more important. Osgood also reported results of semantic differentiation of actual color samples on the part of Navajo and Anglo subjects. There was general cross-cultural agreement as to the connotative meanings of colors. Interestingly, Osgood noted that the agreement seemed somewhat better with respect to the meanings of the actual color samples than it did with the color names used in the prior study. Such an outcome is not surprising, and it serves as a caution against too readily equating verbal and sensory synesthesia.

Two conclusions from Osgood's study are of theoretical import. The first is that synesthetic tendencies (at least those on the verbal–visual level) show generality across members of different linguistic and cultural groups. The generalization in itself may seem merely to affirm the conclusion that was arrived at earlier with respect to pure sensory synesthesia (colored hearing). But the implication of Osgood's results leads further, for a second conclusion we may derive from his findings is that synesthesia is primarily a cognitive phenomenon; synesthesia is related to connotative meaning in general. Similar conclusions were reached earlier by Wheeler and Cutsforth (1922), Vernon (1930), Riggs and Karwoski (1934), and Karwoski and Odbert (1938). This same conclusion is implicit, if not explicit, in the view expressed by Bleuler (1913), who pointed out that certain synesthetic relations (like pitch–brightness) are universal and that colors act as symbols. The dimensions that underlie synesthesia are the same as those that appear to underlie connotative meaning in general.

What synesthesia provides to cognition is, in essence, a shorthand. Synesthesia is not just something that is tacked onto ordinary sense perception and cognition. Rather, it is an integral part of perception and cognition. One of its special roles is to summarize important cognitive distinctions in a convenient and economical way. To use an example of Boring, Langfeld, and Weld (1935), we are capable of *perceiving* ice as cold and heavy or an object as light or heavy by the sound of its fall, and so on. Those are economical modes of perceiving. So too is it often with synesthesia. The cross-modal correspondences between and among the senses serve to highlight, in a convenient manner, important dimensions held in common (brightness, size, affect, etc.). Even when synesthetic responses extend the domain of reference (i.e., when the induced sensations add new qualities, new dimensions) synesthesia is not uneconomical. Rather, it is both enriching (as in the synesthetic responses to music) in its content and economical in its mode—economical, that is, as compared to alternative means of cognitive enrichment, such as linguistic elaboration. In this sense, it may be of some use to treat synesthetic cognition as an *adjunct* (*alternative* being too strong a contrast) to verbal cognition. Synesthetic, cross-modal, sensory cognition is both less abstract and more dense in informational content.

The present interpretation may help to shed some light on one unresolved problem, namely, why synesthesia often seems to disappear as a person grows and matures from childhood to adulthood. Synesthesia has been claimed to be a significant mode of thought in children (Werner, 1940). That synesthesia typically arises in childhood has been noted in nearly every study, although there are occasional exceptions (e.g., Vernon, 1930, reported that his own musical synesthesiae began only around age 14–15). The origin of synesthesia in childhood is in part the reason for the many reports of children's synesthesia (e.g., English, 1923; Lenzberg, 1923; Riggs & Karwoski, 1934; Werner, 1940).

Synesthesia is also more common in children than in adults. G. Stanley Hall (1883) found that 21 children of 53 (39.6%) described the sounds of musical instruments as colored. Révész (1923) estimated that 50% of children are synesthetic. Estimates vary as to the frequency of occurrence in adults. Bleuler and Lehmann (1881) reported that 76 of 596 adults (12.7%) had colored hearing; Calkins (1895) gave a similar value, 15.7%; and Rose (1909), a somewhat lower value, 9.1%. On the other hand, Philippe (1893a) reported that 30 of 150 blind subjects (20%) had colored hearing; many claimed their synesthesiae developed after the loss of vision. In sum, the frequency of synesthesia in children appears to be two to three times that in adults. Because most synesthetes report remembering their synesthesia as far back as childhood, it would seem a reasonable conclusion that whereas synesthesia originates in childhood, some or many child synesthetes lose their synesthesia when they grow up.

Why does synesthesia tend to be lost with age? Probably because it is replaced by another, more flexible mode of cognition (i.e., abstract language). Although synesthesia is a direct and economical mode of cognitive organization, it is not only an overly general and imprecise mode but also an inflexible one. The connotative meanings borne by synesthetic relationships are compact and salient but tend to be relatively fixed. As a child matures and cognitive development ensues, it becomes valuable, indeed necessary, for the child to transfer the meanings from the perceptual–synesthetic to the verbal realm, in which they may be used within a much less restrictive and more tractable framework. This is what Bruner (1964) called the transition from iconic to symbolic modes of representation. Considered in this manner, to the extent that synesthesia transcends childhood and lasts into adulthood, we may view it as somewhat vestigial.

Earlier in this article it was pointed out that synesthesia in its sensory form may conveniently be classified under the general rubric of *imagery*. Given the significant role that imagery plays in cognitive development (e.g., Bruner, 1964), it is not surprising that Werner (1940) called attention to the importance of synesthesia in childhood. Synesthetic perception is a mode of iconic representation. Its importance, indeed the importance of imagery in general, diminishes with the augmented importance of language, that is, of symbolic representation. The present interpretation of synesthesia as imagery is consistent with Paivio's (1971) model, in which imagery precedes language but both develop concurrently as the means to process information. Paivio gave an excellent account of the extent to which imagery in general continues to be an important system in cognition.

Implicit in this discussion is the view that synesthesia is not an isolated phenomenon, separated from nonsynesthetic perception and thought. Rather, synesthesia is a cross-modal manifestation of meaning in its purely sensory, and in one sense its strongest, form. But in its essence synesthesia is not really different from nonsynesthetic, cross-modal meaning nor, in much of its content, from abstract verbal meaning. A corollary is that synesthesia is probably not really lost in the cognitive transition from childhood to adulthood but is merely diminished in its magnitude, importance, and/or salience. The cross-modal matches shift from a purely sensory to a sensory–verbal or even purely verbal realm.

Though verbal synesthesia proper falls beyond the scope of the present article, a few words are in order. There are two forms of metaphoric or poetic expression of cross-sensory relation. One form simply symbolizes sensory synesthesia (i.e., expresses some intrinsic cross-modal relationship). In "Al Aaraaf," Poe asked us to "Witness the murmur of the grey twilight." The other, probably more typical, form creates or points to new or original sensory correspondence, (i.e., expresses some extrinsic cross-modal relationship that is imposed). In "The Anunciation," W. S. Merwin asked us to witness "the blackness/of their shadow growing as it came down/ Whirring and beating, cold and like thunder."

Now we are led to consider a significant difference between synesthetic and nonsynesthetic sensory correspondences. For, whereas synesthetic correspondences tend to be fixed and inflexible, nonsynesthetic correspondences can be quite flexible. Some nonsynesthetic subjects may correlate auditory loudness with visual brightness, others may correlate loudness with darkness, and still others may correlate loudness with brightness on some occasions but may correlate loudness with darkness on other occasions (Marks, 1974). Most likely, such reversals in the way that dimensions align are themselves mediated by language. Synesthetic correspondences may provide a primitive origin containing fixed relationships upon which abstract language can build and provide flexibility.

Verbal synesthesiae (representations of cross-sensory equivalence in language) need not rely on fixed responses to mediate between dimensions on different modalities; indeed, verbal synesthesiae cannot rely on such. In order for verbal manipulations to permit reversals of dimensional alignment, they must rely on a mechanism more complex than mediating responses. Just how that verbal mechanism operates remains a question, but whatever it is, a price is paid for the flexibility it provides: The symbolic manipulations arise at least one step, probably several steps, removed from the sense perceptions described, and thereby we lose the immediacy, the richness, and the vivacity of sensory synesthesia. Sometimes the purely sensory correspondences can be reached or regained, for instance, under the influence of drugs. Thus, Baudelaire (1860) the hashish smoker could perceive, as Baudelaire (1857) the poet cognized, how "Les parfums, les couleurs et les sons se répondent."

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