COLOUR AND MUSICAL PITCH

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Thesis submitted in accordance
with the requirements of the
University of Sheffield for the
Degree of Doctor of Philosophy,
January 1972.

FRONTISPIECE: Each patch of colour represents the chromaesthetic associations with individual musical keys experienced by an artist-musician (JKM). By careful blending of different oils he has matched the colours to his highly specific imagery as faithfully as possible. On the original parchment (30 x 44 cm.) each colour occupies at least 3 sq. cm.; the present photograph fails to reproduce the colours perfectly, and least accurately differentiates the shades of blue. The case of JKM is discussed in APP/2.

This thesis is dedicated
to the memory of my father

Acknowledgments

- to Professor P. McKellar for his great encouragement and guidance to my first steps in the research I now report, to Professor H. Kay, in whose Department of Psychology at Sheffield I have spent six memorable years; and to the Social Science Research Council for the studentship I have held between 1968 and 1971.

- to Professor B. Deane, Dr. R. Bullivant, and all my patient subjects from the University's Music Department: highlights of our association have been the conversations with Mrs. Sandra Preston on which section 5.4 of this thesis is based; and I shall retain most grateful memories of Dr. Phillip Lord.

- to Mr. J. K. Clarkson for his introduction to the decision-time technique employed in Chapter 4, and for his advice on those points where an independent assessment can be so valuable; to Mr. T. Shigehisa and Mr. D. Jerrett for our stimulating discussions touching theoretical points in Chapters 4 and 5; and to Dr. A. J. Simpson (fellow Gilbert & Sullivan enthusiast) for his constant readiness to advise on "matters mathematical" and ALGOL's "tangled skein".

- to Dr. C. P. Spencer, sincere thanks for his help throughout the research; to Mr. P. Geraghty for his generous execution of the graphs and figures; to Mr. W. Dyson and the Psychology Department's technical staff for their assistance with equipment.

- to Drs. R. M. Cook and S. W. Duck for bonhomie; and to the former as skilled photographer.

- finally, I am thankful for all the ways in which my parents have aided the course of my research; and to my wife, Sheila, with whom in many respects this should be a joint thesis: for her countless hours in the organisation of data and bibliography, the checking of manuscripts, and for the benefits of her musical expertise - these have been indispensable.

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Summary

Individual reactions to musical stimuli imply the extraction of more information regarding pitch than a uni-dimensional pitch theory can accommodate; the phenomenology of Absolute Pitch (AP) suggests a rare sensitivity to qualities varying on separate dimensions of 'tone-height' and 'tone-chroma'.

Introspective reports by synaesthetes indicate the coding of both pitch dimensions in terms parallel to those of simple visual sensation. In EXP/A, normal discrimination of tone-height qualities is reflected in the forced-choice equation of low notes and dark colours, high notes and bright; while in EXP/B a quality consistent with the definition of tone-chroma is evident in the systematic association by chromaesthetes of colour-brightness and the cyclic sequence of fifths that underlies musical tonality relationships.

By an objective decision-time technique (EXPS/C and D), the speed of visual judgments is seen to be influenced by auditory pre-stimulation, and vice versa. Individual differences in the intersensory effects observed are dichotomised by reference to measures of Neuroticism and Extraversion. A battery of tests for the identification of 'genuine AP' is presented, and further differences noted in the decision-time responses to tone-height and tone-chroma by groups of AP, non-AP, and non-musical subjects. The systematic fluctuation of colour-tone integration measures across the tonality dimension provides objective support for the tone-chroma effect isolated in EXP/B.

Further confirmation of the chroma effect is noted in a questionnaire study of 'key-brightness' ratings, and each of the pitch qualities is considered in relation to the discrimination of beats arising from mistuned consonances. The possible coding of chroma in AP is discussed, and implications suggested in areas of imagery and aesthetics, intersensory integration, education, musical psychology and musicology.

"From Harmony, from heavenly Harmony

This Universal frame began:

When Nature underneath a heap

Of jarring atoms lay

And could not heave her head,

The tuneful voice was heard from high

Arise, ye more than dead:

Then cold, and hot, and moist, and dry

In order to their stations leap,

And Music's power obey.

From harmony, from heavenly harmony

This universal frame began.

From harmony to harmony

Through all the compass of the notes it ran

The diapason closing full in Man ..."

(From "Song for St. Cecilia's Day',

DRYDEN).

"It is a wonderful thing that science makes it possible to explain the operations of the musical mind in the same attitude that the astronomer explains the operation of the stars ... Astronomy has revealed a macrocosm, the order of the universe in the large; the science of music has revealed a microcosm, the operation of law and order in the structure and operation of the musical mind."

(SEASHORE, 1938).

Chapter One

THE MUSICAL EAR

1.1 MUSIC AND PSYCHOLOGY.

In Plato's cave the images were blurred and sensation shoddy. Music rose above all this, a source of mysterious elevation since the earliest comparison of successive sounds. For 2,000 years music was regarded by the physicist and philosopher as an objective principle governing the smooth coordination of the Universe; its perception was considered of secondary importance. Without doubt the greatest single contributor to the modern theory of music was von Helmholtz. In 'Sensations of Tone' (1862) he pointed out that music does not exist in vacuo - as, for example, "Harmony, heavenly Harmony" - but on the transmission of sound to a responsive mind by the ear; his resonance theory remains to this day an impressive account of the major auditory phenomena. Questions posed by Helmholtz were of immediate interest to the psychologist. The possible inheritance of musical ability was considered by Galton (1869), and, in 1880, Guerney's 'The Power of Sound' discussed most eloquently the role of music as "language of the emotions". The scope of these early enquiries was broad, covering in non-empirical terms the total range of factors that comprises musical psychology today. Yet the questions subsequently posed by psychological theorists of music have been chiefly concerned with one area alone - the estimation of musical attainment and potential.

The development of this specialised interest began between 1883 and 1890, when Stumpf noted a range of individual differences in response to simple tone which caused him to realise the need for objective measures of the underlying sensory capacities. A theoretical analysis of musicality was duly presented by Billroth in 'Wer ist

Musikalisch' (1895); while in the newly established laboratory under Scripture's direction at Yale the first comparisons of test performance by musical and non-musical subjects were made by Hughes (Shuter, 1968). A priority at this stage was to augment the far from adequate fund of terminology for describing the dimensions of tonal sensation (NEXT SECTION); and the chief implications seen in the research that followed were for music education. By far the most consistent influence on musical psychology was exercised by Seashore and his co-workers - notably Stanton (q.v.) - at Iowa. Inventor of the voice tonoscope and the audiometer, between 1897 and 1930 Seashore's prime achievement was in developing the first standardised Measures of Musical Talents (1919, with revisions 1939, 1960). As an index of the relative strengths and weaknesses of psychophysical capacities assumed to underly musical ability, the Seashore battery still has useful applications. Whether such tests adequately reflect functional musical ability has been frequently questioned - by Mursell, Bentley, and Wing (q.v.). In the Wing tests (1948, revised 1962 - Britain's leading standardised battery) an attempt was made to guard against this shortcoming by including sections on musical appreciation. Other critics of Seashore - as Farnsworth, Lundin - have pointed out his lack of justification in assuming a purely innate basis for the capacities under test, and that a poor performance in the tests does not necessarily imply low musicality beyond treatment by practice.

Further tests by Revesz (1920), Hillbrand (1923), Schoen (1923,1925), Lowery (1926,1929), Kwalwasser (1926,1927; & Ruch, 1924; & Dykema, 1930), Hevner (1931), Mainwaring (1931), Drake (1931,1933), and Semeonoff (1940) claimed to measure a variety of abilities ranging through the discrimination of pitch, intensity, consonance, quality, tonal memory, tonal movement, time and rhythm to melodic taste, cadence selection, sight-singing and tonal imagery. In 1926 the sensory dimensions underlying musical aptitude were discussed by von Kries, though the objectivity of his views, as of all previous psychological analysis, was limited by the lack of adequate statistical technique.

In 'The Abilities of Man' (1927), Spearman described his tetrad differences method for the isolation of general and specific factors contributing to the variance in a set of test scores. Factor analytic examinations of musical tests were subsequently made by Wing (1936, 1941), Fieldhouse (1937), Drake (1939), Karlin (1941,1942), McLeish (1950), Vernon (1950), Henkin (1955), Franklin (1956), Whittington (1957), Faulds (1959), Holmstrom (1963), and Shuter (1964). The numerous tests developed concurrent with these studies (vide Shuter, 1968) naturally tended to respect the main factors that emerged. The factors they emphasised - as Memory, Harmony, Pitch, Rhythm and Attitude - represent those sensitivities displayed by the majority of the population samples; and success in a test is dependent on one's ability to make the necessary judgements on the bases that the majority of the population uses.

The attraction of factor analysis is magnetic; its dangers have been discussed by P.E.Vernon (1950). While the impact of factorisation on the course of musical psychology has been tremendous, Vernon's warning against the assumption that a factor embraces the gamut of ability that it pretends to describe has not been heeded; and the theory of music remains incapable of explaining a wide array of phenomena. In Payne's analysis (1967) the outstanding questions -

additional to the study of musical ability - relate "to the nature of the appreciative experience (how one listens to music)", and to aesthetic and affective forms of musical taste. However, to infer from this analysis that each question may be satisfactorily examined in isolation would be to deny that each must surely be related, in any theory concerning it, to each of the others. In the attempt to establish a theory of music at the composite level, its elements should first be identified and population tendencies established in the response that they elicit.

> "Any absolute value ascribed to either musical form or (to the composite) musical response can be but one transient, arbitrary point in a long, evolving series of human values." (HEINLEIN,1939).

Early empirical work on the aesthetic characteristics of single tones and intervals was undertaken by Meyer (1900-1904), Lipps (1902), Myers (1911,1914,1922), Malmberg (1918) and Valentine (1910 onward). The elements of expression and affective value in music as a whole were investigated by Ferguson (1925), Farnsworth (1926), Lowell (1926), Schoen (1925-1928), Heinlein (1928), Pratt (1931), Sorantin (1932), Hevner (1930-1937), and Rigg (1933-1940), with their main factors being those already tackled by the prognosticators of musical ability. Concise histories of the experimental psychology of beauty in music and in general are provided by Farnsworth (1950) and Valentine (1960, 1962). The main problems in musical psychology and their study in the laboratory and social contexts have been summarised by Revesz (1946,1953), Kwalwasser (1955), Mueller & Hevner (1956), Farnsworth (1958), Gedda (1961), Whybrew (1962), Fosha (1964), Malzmann (1965), Tarrell (1965), Teplov (1966), Wing & Bentley (1966), Lundin (1958, 1967), Cady (1967), and Shuter (1968); and cross-cultural correspondence between the elements of music has recently been discussed in detail by Merriam (1964).

Yet since the 1930's the cognitive aspects of musical psychology have received little experimental attention. Factor analysis was not the sole determinant of musical psychology's main course; the decline of tonal phenomenology at that time resulted in part from the development of psychological scaling techniques by Stevens and his colleagues - q.v. Stevens (1951), Harris (1969) - and the growing knowledge of the ear's mechanism provided adequate explanation of the normal auditory sensations. But factor analysis reflects a tendency in psychology to combine functions of the majority whilst ignoring minor variance; in this way the psychologist produces tools for the description and prognostication of the norm while restricting the scope for finer analysis. As Taylor (1958) points out,

> "Lewin's (1931) warning against applying in psychology the Aristotelian notion that frequency of occurrence is equivalent to lawfulness fell on deaf ears."

And as a result the contrast between the perceptual worlds of those at the extremes of the musicality range is little understood.

Perhaps the early work in musical aesthetics was premature. Imagery, the area that Galton had pioneered, represented so many compound variables - and, in the absence of other than the introspective method, had been tackled so inadequately - that its rejection by the behaviourist school was inevitable. The study of affectivity, blanket term for a similarly heterogeneous collection of fancies, went out of favour too - and when Guilford declared 'There is System in Colour Preference' (1940) he was already too late. The behaviourist's argument against "mentalistic" psychology was at the time a powerful one; for even when an observation conflicts with normative gospel there are temptations. One of these is to dismiss the phenomenon as the odd one in a hundred; a second defence is rationalisation - an effort is made to squeeze the observation back into line by playing down its theoretical importance; a third reaction would be to dismiss the line altogether and form a new one, but this occurs less often. The gradual return of some of the 'ostracised' topics began in the 1950's; advances in neurophysiology helped the psychologist towards a revaluation of subjective phenomena as "parts of the inner workings of a theoretical model" (HOLT, 1964). During the 1960's considerable headway was made in the study of visual processes (Hubel & Wiesel,1959,1962; Neisser,1966); while in view of the various unresolved disagreements regarding tonal sensation it is perhaps not as remarkable as Diana Deutsch suggests (1969) that musical psychology has remained in the background. For the construction of his model for musical sensation the psychologist has new techniques, new facilities, new allies; his next undertaking should be the new phenomenology.

1.2 THE ATTRIBUTES OF SOUND.

The early analyses of sensation had little empirical foundation, though it is significant that in their attempt to understand the general phenomenology of sound the psychological theorists gave to the qualities discerned by the musical ear especial consideration. It is well to observe at the very outset that these theorists (Helmholtz, Mach, Stumpf) had as lief omit the attributes of musical sensation from their thoughts on hearing as disregard the importance of colour sensation in vision. Ogden (1918), distinguishing between properties of tone, vowel and noise, concludes that

> "lack of functional (discriminative) capacity explains amusia and also some forms of speech deafness. Music, oral speech and significant noise are all results of comparison and judgment, in which the structural elements of content furnish the basic data."

The question of defining the structural elements was a controversial one, and never fully resolved. As psychology evolved from the philosophy of science two main attributes were developed that sensation might be systematised: sensory content, stated Wundt (1874), is characterised by variations in Quality and Intensity. A formal doctrine of attributes (Eigenschaft) was put forward by Kulpe (1893) with the addition of Duration as third 'attribute' of the five main senses, and Extension as a fourth for vision and touch. The concept of attribute serves the philosopher and psychologist in separate ways, and the shortcomings of the Wundt-Kulpe quartet of sensory elements may be debated, likewise, on two different planes. As it stood the attribute poised ambiguously between being a property of the physical stimulus and one of the percept. In 1909, Titchener - for the psychologists - added a fifth attribute later named Attensity, by which each of the previous four should be qualified. Titchener's attribute, which describes the perceptual status of a stimulus in the sensory field attended to, began the development of an analysis that was presumably directed at the eventual definition of all elements of sensory experience from a united psychological standpoint.

This, of course, was not achieved. It is from this point - 1909 - that the psychologists' real differences over sensation derive; and, in so far as the explanation of any of the senses has been undertaken, the analysis of auditory sensation has been the least satisfactory. The psychologist's first impulse, as Boring (1942) describes, was for freedom:

> "....freedom in the use of descriptive terms ... If tones besides being high and low, loud and soft, big and little, of long and short duration, are also bright and dull they wanted to say so ..."

In order to explain musical as well as non-musical qualities of auditory sensation, they sought to define the elements of that very area of cognition where individuals most disagree; for, as a stimulus becomes familiar, it is interpreted in the light of the unique complexity of associations established by individual experience. Thus, qualities of pitch (the sensory correlate of acoustical frequency) may indeed be described as high, low, or any characteristic apparently unrelated to the basic sense impression.

> "That the province of tone-sensation offers an analogy to space, and to a space having no symmetry, is unconsciously expressed in language. We speak of high tones and deep tones, not of right tones and left tones, although our musical instruments suggest the latter designation as a very natural one." (MACH, 1906).

The adoption of Volume as an attribute of tone was suggested by Titchener (1909/10); since used as a synonym for loudness or intensity, the term volume originally referred to the observation by Stumpf (1890) that low notes seem large and high notes small. In fact such associations may derive from sundry cultural factors, while the observations (CHAP.2) that children demonstrate them even more readily than adults suggests that the associations may have a physiological basis also. An equation of Brightness with pitch was originally noted by Mach (1886) and later upheld by Brentano (1907), Stumpf (1914), Kohler (1915) and Rich (1919). A further attribute - of Vocality - was apparently the result of confusion between the observation that tones sound like vowels and the fact that the vowels are constituted by differential frequency bands.

The main development in tonal phenomenology during the 1920's derived from the psychophysical study (Rich, Halverson, Ogden: q.v.) of perceptual relationships between the attributes, leading in 1934 to Stevens' postulation of the separate tonal concepts of Pitch, Loudness, Volume and Density. The Density attribute gave expression to a further qualitative dimension of tonal compactness (hardness) vs. rareness (thinness). Distinctions of this qualitative genre, made either as a function of the overtone structure of a note or in simple logarithmic relationship to the fundamental frequency, are all that the non-musical ear requires: the normal discrimination of tones is accomplished by judgment of their relative position to each other on the frequency dimension alone, and the greater the distance between them the less they seem alike. Differences in intensity/loudness are evident regardless of musical ability.

Yet tones dissimilar on the linear pitch scale may be judged musically similar in terms of consonance/dissonance. After the unison effect of two identical frequencies sounded simultaneously, the greatest consonance is between notes separated by the interval of an octave, having a vibration ratio (higher note to lower) of 2:1. When heard

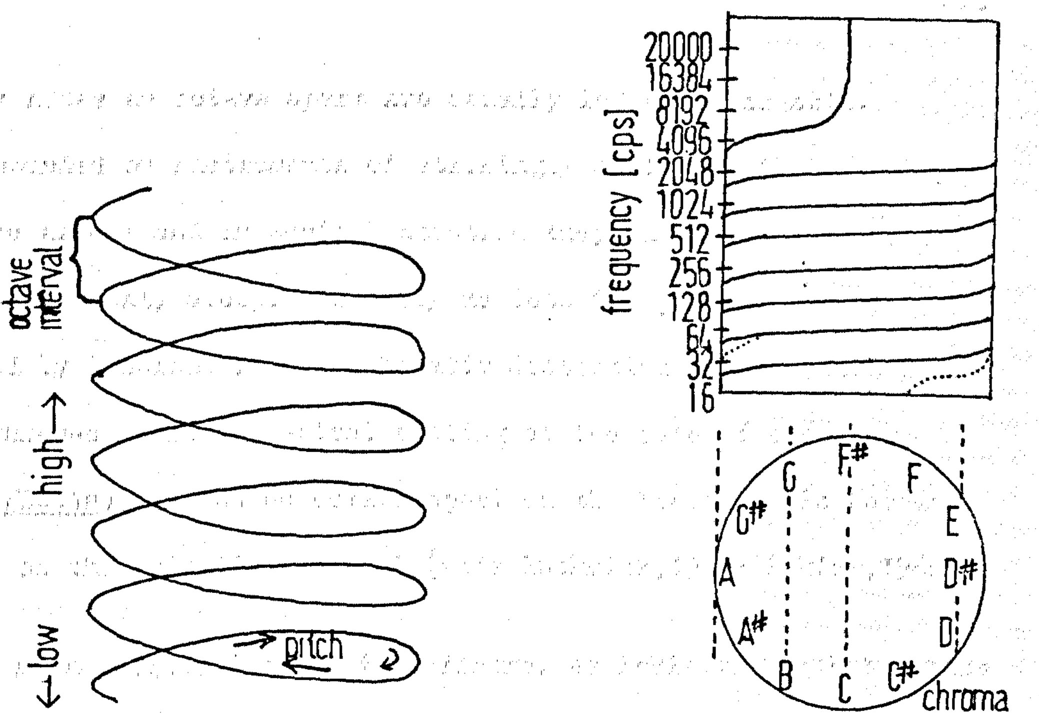


FIG. 1a. Impression of the Drobisch spiral

FIG. 1b Representation of frequency chroma [after Bachem, 1948 p.705]

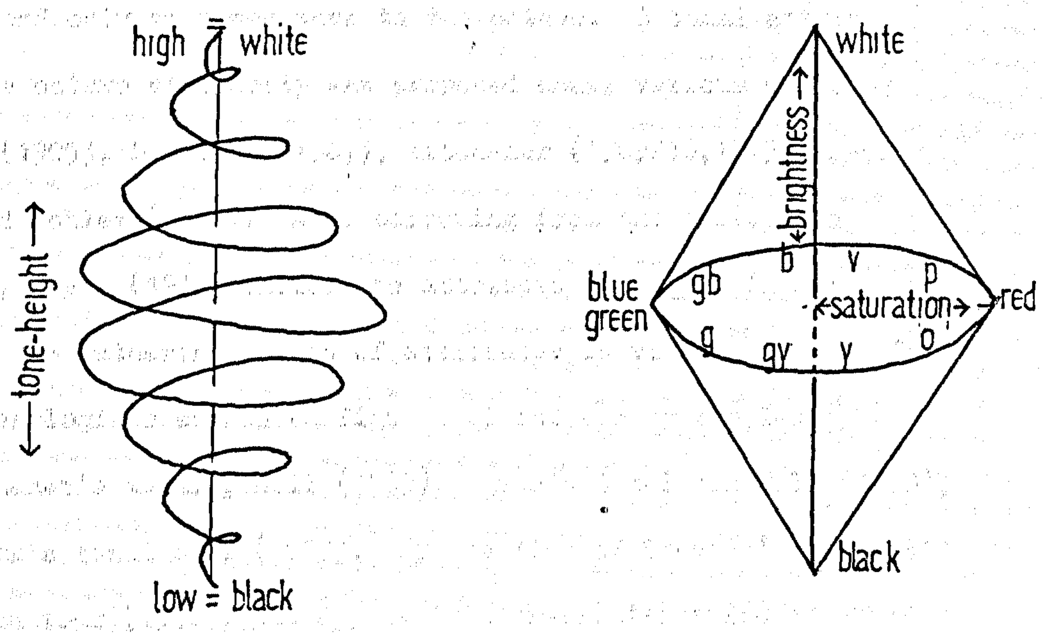


FIG. 1c Helical impression of Brentano's pitch attributes

FIG. 1d The colour spindle [Munn, 1951]

FIGS. 1 Helical representations of auditory and visual sensations.

together notes an octave apart are usually indistinguishable: unless sounded on instruments of strikingly different timbre, they are heard as one and in musical notation they share the same name (A, Fsharp, Bflat, etc.). As early as 1846 the phenomenon was expressed by Drobisch in his schematic distortion of the pitch scale into a three-dimensional spiral cycling at the rate of once per octave (FIG.1a); notes an octave apart on the linear scale become adjacent on the spiral's vertical (vide Ruckmick,1929; Pikler,1966).

The main shortcomings of this figure, as indicated by Ebbinghaus (1902), are (a) that tones adjacent on the ascending spiral are most dissonant in terms of tonal fusion, and (b) that while notes separated by the interval of a fifth, 3:2, are represented as near-diametrical opposites, their simultaneous presentation yields a degree of tonal fusion second only in consonance to the octave. A tonal attribute to describe octave similarity was proposed under various names by McDougall (1905), Brentano (1907), Titchener (1909/10,1915), Revesz (1913), and Kohler (1915); and, borrowing from the musician's vocabulary, Meyer (1914) called the attribute Tonality. In attempts to express the gathering legion of attributes in visual mnemonic form the phenomenologists suggested figures of increasing complexity - e.g. Titchener's tonal pencil (1909), Ogden's tonal manifold (1920), and Ruckmick's tonal bell (1929). By the time of Stevens' charts of isophonic contour (1934), the apparent inter-relationships of this "flurry of attributes" (Boring,1942) permitted the tonal sensation a simple spatial formula no longer. In that it had begotten the experimental techniques from which modern psychophysics developed, the phenomenological analysis of sensation was considered to have served its purpose, and by the 1940's was discarded. The attributes, taken separately, fared as follows:

- Loudness and Pitch were retained as the basic experiential correlates of the acoustic dimensions intensity and frequency;
- Volume became the label for subjective loudness as it varies differentially with pitch (Fletcher & Munson,1933) and with intensity held constant;
- Tonality (i.e. octave similarity) was considered unnecessary following the discovery (Fletcher,1934,1940; Schouten,1938 to 1940) of the ear's nonlinear properties and production of aural harmonics;
- Brightness and Density were suggested by Boring & Stevens (1936) to be different terms for the same quality, whose origin remains, for the time being, enigmatic.

The new developments in psychoacoustics, especially the observations of subjective and residue phenomena, required that strict resonance (place) theory as offered by Helmholtz be at least modified. By the late 1940's a series of revisions to auditory theory were suggested which shift the emphasis from mechanistic (e.g. wave and pattern theories) to electro-mechanical and periodicity processes. The phenomena on which research has concentrated (perception of pulses and noise bursts, masking effects, interaural phase, binaural clicks, auditory fatigue and localisation processes) are such that the average non-musical ear may demonstrate; and the facts of recurrent tone quality, consonance and dissonance, musical interval and harmony sense, tonal recognition and recall, have been dismissed as simple functions of habituation, physiologically irrelevant. (Pikler,1955). Indeed, certain theorists (Herbart, Sully, Stumpf) have denied the most central phenomenon of octave similarity altogether (Revesz,1953).

Pikler (1955) reminds us of the original attempts to include music as well as speech and noise perception in the theory of sound and discusses the reaction against a foundation of hearing on phenomena of the twelve-note musical scale. We see that in the existing theoretical framework the musical phenomena could only complicate matters to an apparently insoluble degree, and that "the revised theories of hearing had no alternative but to discard the diatonic aspects of hearing" as by implication "apriori unscientific". But, as Diana Deutsch (1969) points out,

> "the ability to recognise music is quite distinct from simple pitch recognition or discrimination. It requires a mechanism which can abstract the relational properties existing in tonal combinations."

She proposes a neural network which, though non-heuristic, may help at the behavioural level "to rationalise the psychology and aesthetics of music by providing larger and more fundamental building blocks out of which all music must be built". This is the new phenomenology's basic task.

1.3 LEVELS OF THE PITCH CAPACITY.

A common objection to attempts to postulate universal concepts of musical sensation has been that the scales on which the musical systems are built differ from culture to culture. The system of intonation predominant until the Middle Ages was that devised by Pythagoras (c. 550 B.C.). In contrast to the modern twelve-note scale the Pythagorean system contained only seven notes; the Brazilian Pan-Pipes, on the other hand, have an octave of twenty-three notes, and this range of variation may be due to a number of factors - for example, instrumental requirements, mathematical speculations, or cosmological concepts. Comparative musicologists, however, have established (Jeans,1937; Revesz,1953; Longuet-Higgins, 1970) the important role of each of the consonant intervals (octave, fifth, third) in the most basic of musical systems. That the consonant relationships are applied to incoming tones by the ear itself is shown by the phenomenon of aural harmonics; and since the formulation of overtone theory (Sauveur,1701) it has been evident that the sine qua non of musical sensitivity in general are the mechanisms for <u>sensation of pitch</u>.

The pitch sense does not involve merely discriminative prowess. Wing (1948) and Trotter (1967) report cases where superlative acuity for pitch goes hand in hand with the inability to master a simple melody. Indeed, as work that shall be discussed in later chapters indicates (Sabaneev, van Krevelen, Bachem), far too many objections to the psychophysical validity of the musical scale (e.g. by C.Lorenz,1891; Stevens, Volkman & Newman,1937) have centred upon asymptotic pitch differences that cease to have perceptual significance when prime consideration is being given to the structural inter-relationships that music emphasises. And while the 'psychophysical pitch scale' established by Stevens et al. (1937) has been unquestioningly accepted by most researchers as the 'true' representation of frequency sensation, its calibration - itself of dubious precision as Pikler (1955) points out - was based on an assumption that pitch differences are equally discriminable throughout the range; this, as the most musical of subjects will reveal, is by no means so. And, in a further respect, the Stevens scale is even less adequate.

For (leaving aside the musical phenomena mentioned hitherto, accepting for the moment the arguments of Herbart and others who preferred to find dissimilarity in the octave) we must still reckon with the indisputable facts of the ear's capacity for judgment of pitch by <u>recognition and recall</u>. The contrast between the ear's capacity to distinguish about 350,000 successively presented tones (Stevens, 1938) and the relative inability to identify tones presented in isolation, has been pointed out by a pioneer of <u>information theory</u>, Pollack (1952, 1953). Pollack found the ability of an unselected group of subjects to extract information from tones in this way limited to about 2.3 bits, the equivalent of correct classification of the tones into five pitch categories. Miller (1956) indicates that this performance may be improved in three ways: (1) by relating the judgment tone to a referent, possibly internal as for example the lowest note in one's vocal range, (2) by increasing the dimensionality of the stimulus, i.e. the number of variable attributes, or (3) by making a series of absolute judgments the nature of which Miller does not specify.

Since Mozart was a child (b.1756) documentary evidence has shown that rare individuals may indeed make pitch judgments which are of an accuracy far in excess of the 2.3 bits attributed by Pollack to the normal ear:

> "He (Mozart at 7 yrs.) had on a certain occasion played the violin of his friend Schachtner ... Some days after, Schachtner, on entering the house, found the boy amusing himself with his own little violin ... On a sudden he (the boy) stopped, pondered awhile, and then added, "If you have not altered the tuning of your violin since I last played upon it, it is a half a quarter tone flatter than mine here". At this unusual exactitude of ear and memory there was at first a laugh, but the father thought proper to have the violin sent for and examined and the result proved that the boy was perfectly correct."
>
> (SCHOLES,1970,p.2).

Oxford Professor of Music Sir F.A.G.Ouseley (1825-1889) was capable of similarly surprising observations: that the wind whistled in D, or that the clock struck in B minor - the literature on Absolute Pitch abounds with such anecdotes - ("Only think, papa blows his nose on G"). And Ward (1953) estimates that a typical case is capable of identifications exceeding 6 bit accuracy, or over 70 different frequencies in the 50 to 4,500 cps-range (100 per cent accuracy).

Yet as Stanaway, Morley & Anstis point out (1970) much of the published work on absolute pitch has been of little value because neither the experimenter nor his subjects possessed it: this lack of first-hand experience of the absolute pitch capacity has caused widespread confusion over the abilities comprising it, and Stevens (1951) states

> "there is probably no field of psychology in which the terminology has been more confused ... we must have (1) agreement on a definition of absolute pitch and (2) careful measurements with controlled stimuli on (3) an adequate sample of listeners ..."

before we can be sure of our explanation for the anomaly. In spite of 90 years of study by psychologists and acousticians, absolute pitch continues to elude a satisfactory explanation. But the problems of pitch perception in all its forms must surely be settled before we can attempt to explain the higher problems of musical perception and cognition. In the next section a comparison is made of the main views of absolute pitch, pending a conclusion as to the exact abilities that define it.

1.4 ABSOLUTE PITCH.

> "People who claim to be able to place the pitch of any given musical note, without reference to some external standard but purely "by ear", seem to be regarded by many non-musicians as either misguided or dishonest. Yet musicians are quite familiar with the phenomenon, and recognise that a very reliable and accurate "sense" of this nature occurs in a small minority of their number, who are described as having "absolute pitch".
>
> (CARPENTER,1951).

Carpenter observes the scepticism with which claims to a truly 'absolute' sense of pitch are regarded even today. The 'placing of a note' may be demonstrated in two ways: by (a) Recognition - the identifying of a given note by its frequency or musical name - and (b) Recall - the adjusting of a variable frequency (e.g. sung/whistled/hummed) to a level satisfactorily similar to that of the given note. Certainly, claims to these abilities - without being intentionally fraudulent - often confuse the absolute pitch capacity (AP) with the well-developed relative pitch sense (RP); thus our criterion for an absolute judgment shall be that neither an external nor consciously produced internal pitch standard is used as referent.

The AP phenomenon ('Perfect Pitch' to the musician) was introduced to psychology by Stumpf (1683), himself a musician and familiar with the rare claims to the ability. In 'Tonpsychologie' he postulated its dependence on a memory tone - violinists, for example, occasionally claim an unusually accurate memory for the note A from which their instruments are tuned, while pianists have a certain tonotopic regard for the centrality of C; Stumpf himself had a persistent tinnitus of about 1,500 cps which served him as admirable referent. This interpretation, renewed by Seashore (1938,1940), may be contrasted however with that formerly held by Wallaschek (1892) and Rupp (1915): that the placing of a note by its conscious relation to a single referent is but one of the means to an accurate judgment, and that in AP a whole <u>internal reference scale</u> of notes may be retained for this purpose. Support for their contention lies in the frequent observation (Boggs,1907; Revesz,1913; Weinert,1929; Petran,1932; Bachem,1937) that in certain subjects each judgment is accompanied by a good deal of hesitation and humming, while others give their response immediately and disclaim any conscious reference to a single standard whether of internal or external origin.

Thus, in the experimental approach to AP, of prime importance is that some measure of <u>judgment immediacy</u> be provided; this a number of leading investigators have failed to consider (Riker,1946; Neu,1947; van Krevelen,1951; Cuddy,1968,1970,1971), and the resulting confusion between AP and an RP operating by interval reference seems in itself to have led to a belief that possessors of AP should also display extreme accuracy of <u>pitch discrimination</u>. Seashore (1938) believed that

> "the term (AP) probably should be restricted to possession of the ability to identify tones by much smaller steps than those of the musical scale, for example, from 0.01 to 0.1 of a tone";

and Wallace (1914) reflects the view of Wilson (1911) and Warren (1919) in saying that the term

> "appears to be applicable to a condition in which the ear is hypersensitive to a fixed standard of tuning, and rejects as false in intonation all sounds which do not coincide with it".

This confusion, recognised by Petran (1932), is not simply one of labels misapplied. Neu (1947) defines AP as "nothing more than a fine degree of accuracy of pitch discrimination". Yet, as van Krevelen (1951) stresses, "the ability to discriminate does not necessarily guarantee the ability to recognise or identify"; and although Oakes (1955) found a positive relationship between performances at pitch naming (PN) and discrimination (PD), he admitted higher relationships between each of those and the amount of general musical training - no causal relationship between PN and PD may thus be inferred. Sergeant (1967) presents similar findings, and further argument for the view will be derived from a concept of necessary "flexibility of the absolute reference scale" to be suggested in CHAPTER 5.

The fact of AP that has caused its investigators the greatest puzzle is its sheer rarity (Ward,1970): if the ability were ubiquitous it would be little more surprising than the recognition and recall of colours. The amply demonstrated fact that, by training, pitch placing ability may be improved (Meyer,1899,1956; Seashore,1919; Mull,1925; Wedell,1934; Riker,1946; Neu,1947; Brammer,1951; Lundin,1953) has led to the view described by Ward (1963)

> "that the ability is not "special" at all, that the accuracy of pitch-naming shown by the best subjects simply represents the tail of a continuous distribution of the trait ..."

and which we may characterise as the 'learning' theory of AP. The extreme proponent of this viewpoint is Oakes (1951) who accords heredity no possible influence in the matter. Such immoderation is criticised by Jeffress (1962):

> "To the parsimonious, the idea that the human race comprises two populations, one capable of developing absolute pitch, the other not, is offensive. There is one population too many."

At its present state of unravelling, the AP phenomenon poses its researchers two main questions:

(1) Is there a certain pitch ability which, in that it relies on comparisons with no single referent, may be described as 'truly' absolute? and, if we believe that there is,

(2) On what is the 'internal reference scale' based?

Modern research work, (Terman,1965; Vianello & Selby,1968; Cuddy,1968, 1970,1971), does not pretend to tackle either question, concentrating instead upon the improvability issue, presumably in the hope of minimising the need for that offensive "population too many". And as Cuddy points out (1968),

> "one can always choose to define absolute pitch so as to exclude all cases where some kind of formal training can be detected."

Since, to the writer's knowledge, no case is reported of a non-musical AP possessor one might almost conclude that Cuddy's statement renders the learning theory a logical necessity.

However, this conclusion would fail to take into account the work between 1937 and 1955 of Bachem. No other investigator has done more to clarify the issue and to argue for its possible genesis. In effect Bachem recognised that before any of the above questions may be answered the phenomenology of AP must be probed and the rationale established for a rigorous empirical examination.

His work takes the issue several steps towards meeting Stevens' three demands for definition, methodological precision, and adequacy of sample (mentioned above). From a theoretical point of view Bachem was almost as extreme a hereditarian as Oakes an environmentalist. Himself a possessor of AP, he professed "amusement" at the fact that so much previous work had been conducted by non-possessors on non-possessors, and firmly regarded AP as capable of being inherited.

A number of previous observations are cited by him in evidence of this (1940); viz:

- a case of AP in a 3 yr. old prodigy reported by Revesz (1925);
- the fact that the same child's parents had the ability also;
- five prodigies of his own knowledge, aged between 4½ and 8 yrs. all with AP, and three of which had relatives with the ability;
- that 41 of the 103 claimants to AP whom he had studied (1937) also had AP relatives;

and he interprets as necessarily inherited the 'individual factors' variously suggested by Stumpf (1883), von Kries (1892) and Abraham (1901). Neu (1947,1948) believed that Bachem was too dogmatic in overlooking the role of the environment; and Jeffress (1962) argues that

> "the very circumstances which have caused people to believe the trait to be inherited are those that would bring about its 'imprinting'. The children of people having absolute pitch are sure to be examined early for the existence of the trait and their first fumbling steps rewarded. In a home where the parents cannot tell 'c' from a coalscuttle, no such hospitable environment for growth of the trait will exist and the child will learn do,re,me in school with the other children. He will acquire relative pitch like the rest of us".

In offering an 'imprinting' theory of AP, Jeffress follows similar emphases on early experience by Copp (1916) and Watt (1917) - the latter suggests that AP may even be acquired early by all and lost (or 'unlearned') by most. Ward (1963), in the most comprehensive review of AP research to date, sees an early learning theory as quite feasible - it is certainly a more heuristic notion; as Cuddy believes (1968), to prove that AP is not innate is logically impossible anyway.

Yet Bachem never attempted to deny an environmental influence completely, and (1940) mentions his knowledge of 16 AP possessors who were congenitally blind: none of the eleven in his (1937) sample had parents with AP. Weinert (1929) also mentions 3 cases out of her sample of 22, and to these may be added a case (PR) known to the present writer. (PR himself believes, quite rationally, that the customary good hearing of the blind person is due to the constant exercise of the faculty, though does not associate his own AP with being blind since he claimed that the AP was manifest at the age of 3 yrs. while the blindness developed much later.) Bachem's final conclusion (1955) regarding the genesis of AP is as follows:

> "It is evident that inheritance, attention, and experience are the most important factors for the creation of genuine absolute pitch, inheritance being of prime importance in the talented musician, attention representing the most important item in the blind, and experience determining the degree and extent of the final product, particularly in the professional musician."

On this unashamedly general view no-one has yet improved.

But how is the existence of "genuine" AP to be demonstrated? - for Bachem's evidence demands that the strict environmentalist at least reserve judgment on the ability's existence. Taking the Tonality attribute from the phenomenologists and (by which to represent it) a helical figure similar to those of Drobisch (FIG.1a) and Revesz (1913), Bachem (1937) put forward this scheme (FIG.1b). The pitch sensation is divided into two separate components: tone-height, which varies with the logarithm of the frequency in the same way as the conventional pitch concept; and tone-chroma, being a quality peculiar to each note of the twelve-note scale and recurring at each octave cycle. Thus,

> "the name C-chroma shall refer to the common aspects of all the C's (C-ness) and the general term "tone-chroma" shall point to the underlying quality of any tone and the tones in octave periodicity with it".

The normally sensitive ear recognises tone-height alone, whereas the additional knack of an AP possessor is the identification of chroma.

Arguments for a two-component theory of pitch had already been given by Revesz (1913): that

(1) near the thresholds of pitch discrimination, quality (=chroma) differences are noticeable but tone-height differentiation is impossible;

(2) in the highest and lowest ranges of musical tone, chroma disappears while the tone-height is still recognised;

(3) in a case of 'paracusis qualitatis' reported by Liebermann & Revesz (1914) every tone within the range 792 to 3,300 cps had a single octave-recurrent quality (= Gsharp-chroma) while the tone-height advanced normally; thus tones in the lower part of the paracustic range were judged as 825 cps, in the middle part as 1,650 cps, and in the highest part as 3,300 cps;

(4) many noises have no tone quality (chroma) though nonetheless possessing tone-height.

Bachem (1950) adds more:

(5) "Tones coming from different sources (violin, flute, singing, whistling, tone variators) ... can be well compared as to their chroma, but a tone height comparison is practically impossible, judgment errors of one or two octaves occurring..." (cf. Baird, 1917: 'the illusion of the octave');

(6) "The proper recognition of tone chroma, associated with the failure to recognise the correct tone height, was pointed out by Helmholtz (1862) ..." in his imputation of octave errors in pitch judgments by the musicians Tartini and Henrici;

(7) "Brentano (1907) also distinguishing between the "individual tone colors" (chroma) and tone height, compares the former with actual colors, and the latter with the gray series from black to white. While the "tone colors" are saturated in the middle part of the musical range, they become more and more mixed with black and white toward the lower and higher ranges respectively. (FIG.1c). Therefore, the tones are recognised better in the middle part than at the extremes" (Abraham, 1901; Maltzew,1913).

As explanation for the second observation above, Bachem (1948) proposed a notion of <u>chroma fixation</u> at thresholds slightly within the extremes of the auditory spectrum, and reports a further case of 'paracusis qualitatis' interpreted as a disturbance of chroma fixation following a shell explosion. (These concepts are also to be discussed further in CHAPTER 5).

Having propounded his (1937) rationale, Bachem proceeded to the first definition, based on empirical evidence, of a hierarchy of AP types; by laboratory and questionnaire techniques a total of 103 claimants to AP was studied and a variety of differently produced tones (electronic, sung, whistled, on different musical instruments, bells, glasses, and car-horns) was presented for identification. Bachem classified the sample into the following hypothesised AP levels:

(A) Genuine absolute pitch based on immediate recognition of tone chroma:

- (I) Universal
  - (a) Infallible for every range of all musical tones, even noises - N=7;
  - (b) Fallible for most musical instruments with errors of semitone and octave - N=44;
- (II) Limited
  - (a) as to region - N=8;
  - (b) as to timbre - N=5;
  - (c) as to both - N=7;
- (III) Borderline with (B) - 17 subjects inaccurate, 2 others inaccurate and variable.

(B) Quasi-absolute pitch based on a standard and the interval sense; 3 subjects operated from an aural standard (as violin A or piano Middle-C) and 10 others from vocal cues (singing/humming); as Ward notes (1963), there is clearly little of a truly absolute nature about these judgments.

(C) Pseudo-absolute pitch based on estimation of tone-height; (considering the poor performances characteristic of the 7 subjects who came under this heading - responses slow and accuracy minimal - it is somewhat surprising that Bachem felt the need for this category at all).

From a comparison of genuine AP performance with normal pitch estimation, Bachem (1950) indicates the following characteristics which serve to differentiate the two, and support the tenets of his theory:

FIG. 2a Normal pitch estimation based upon tone-height

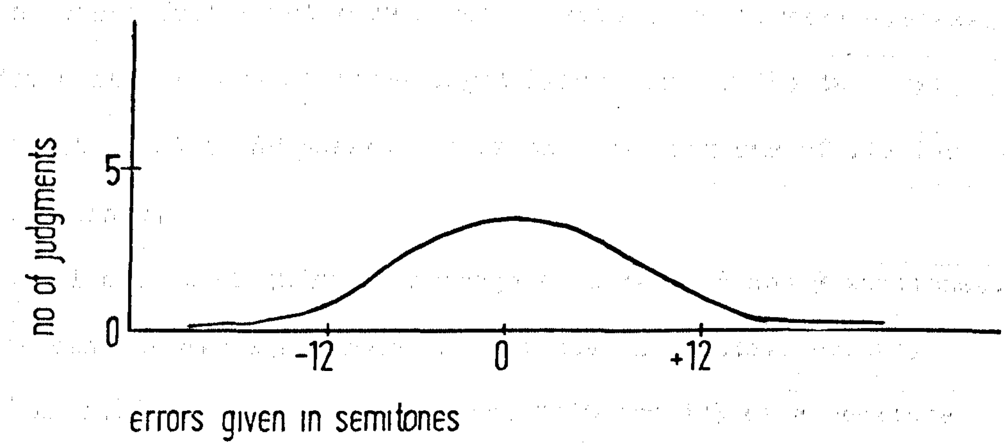
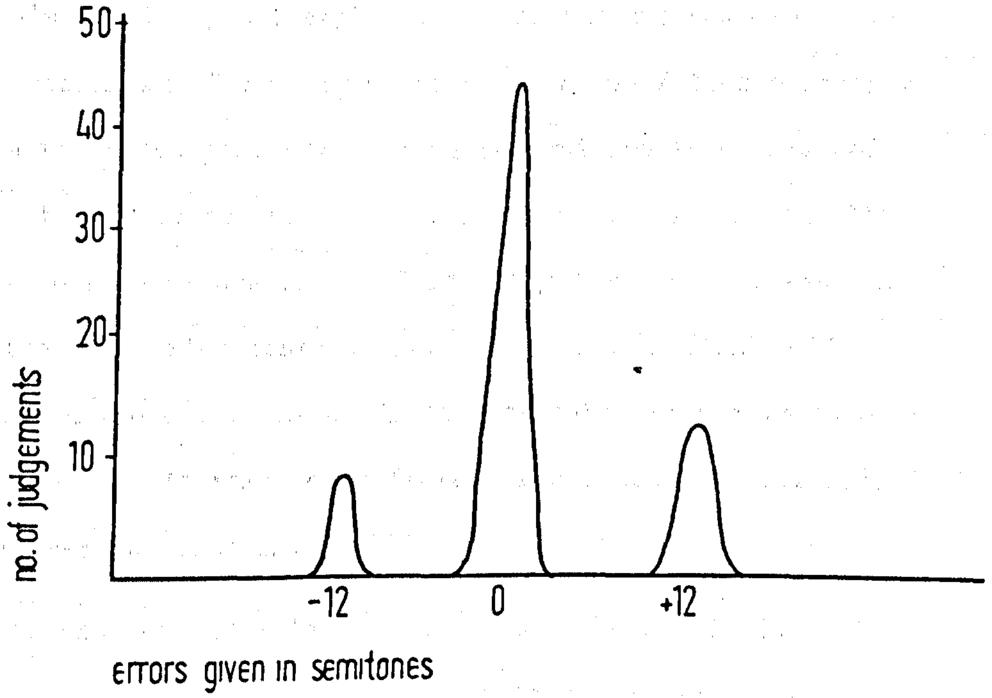


FIG. 2b Absolute Pitch estimation based upon tone-chroma



FIGS. 2 Distributions of accuracy in pitch identification

- while the error distribution of normals follows the general distribution curve (FIG.2a), that of AP subjects shows sharp maxima at octave distances (FIG.2b);
- an octave fusion not recognised as such is by normals mistaken for a single tone of tone-height lying between the two components, but by AP possessors is mistaken for one of its two components;
- normal errors of judgment average at between 5 and 9 semitones, whereas the average errors (notwithstanding octave errors) of AP subjects amounts to between 1/16 and 1/5 of a semitone;
- the accuracy of normals largely depends on familiarity with the timbre of the sound, which that of AP possessors does not;
- at the extremes of the range normal accuracy is greatest while AP accuracy is least.

Bachem's physiological explanation for the two components (1950) involved a mechanism of converging cochlear nerve fibres operating by a simple resonance process: chroma recognition is understood as a fine sensitivity to primary and secondary maxima in the basilar pattern, while non-possessors of AP identify through localisation of the centre of basilar disturbance. The latter notion may be used to explain the different subjective tone-height qualities of tones with the same 'chroma' on different instruments - i.e. with a different overtone pattern.

The influence of Bachem's work has yet to be realised. From both introspective and theoretical standpoints the basic notions are attacked by Meyer (1956):

(1) "A friend and I ... practised memorizing tone height about an hour or two per week for six months (until both of us) named two-thirds of the test tones correctly. We were sure that we had not reached our limits; but we discontinued the practice because ... the ability obtained did not appear worth the time spent in acquiring it. Years later we forgot most of it. We never noticed any 'tone chroma' but perhaps we were just too dull for that."

(2) "Dr. Bachem relies on this "strong association with the octave periodic elements of the tone scale". He forgets that - if aural harmonics existed - they would also produce strong associations with the duodecima (not to mention the fifth partial). The result would ... surely play havoc with identifying scale notes, for a mistaken g-name for C would be an enormous, virtually ridiculous error in absolute memory."

Meyer's steadfast opposition to the aural harmonic phenomenon as conflicting with his own hydraulic theory of hearing (1928,1949, 1950) was soon to be defeated in an exchange (1957) with the physiologists Chocolle & Legouix, Lawrence & Yantis. His claim to a 66% accuracy in pitch identification can hardly be compared with the total accuracy displayed by cases throughout the literature, nor "the time spent in acquiring it" with that of the child prodigies mentioned above. And observations suggesting that the confusion of a note and its fifth may be less ridiculous than Meyer supposes are discussed in CHAPTER 4. One criticism by Meyer is justified, but it merely consists in refuting Helmholtz's imputation of octave error by Tartini (vide (6) above).

Certainly, Bachem's extension of the Helmholtz theory could not be accepted in its present form, and in modern acoustic theory a tone-chroma concept is not admitted. Indeed, as Pikler (1955) points out, these new hearing models tacitly imply AP for everyone - which, if AP is to be defined in Bachem's terms, is clearly untenable. Pikler regards the need for new attention to the AP phenomenon as crucial:

> "we refer to the neglected facts of internal pitch implying reliable auditory operations without physical stimulus and revealing the role of the auditory cortex in the process of hearing".

In his own account of genuine AP - the digital power-spectrum analyzer model of hearing (1954) - Pikler relies on a distinction between physical and psychophysical time-flow:

> "both neural time and sound source's time (e.g. a reference oscillation) represent local time flows. Generally these two time flows are asynchroneous ... In the special case of absolute pitch a fair synchrony exists."

The time-flow theory, in supplying the basis for an internal pitch standard, has no need of a two-component concept; and a possible technique for demonstrating the drift to asynchrony is reported by Harris & Pikler (1963). In fact, the only two persons with AP whom they subjected to the technique (for compensatory and pursuit tracking of pitch) "were occasionally out-performed by one or other of those without". And by 1966 Pikler is happily referring to chroma as one of "the three dimensions (inc. loudness) of the tonal species". The importance of Bachem's work thus lies in his rational definition of a process (so far unassailed) by which a 'genuine AP' ability may be identified.

In the sixteen years that have elapsed since Bachem's final paper (1955) four other writers have echoed the chroma concept; Shepard (1964), in demonstrating the auditory modality's compelling 'circular staircase' illusion, asserts

> "the demonstration of a consistent circularity in the judgment of relative pitch raises a serious question, I think, as to the adequacy of a single, linear scale for this subjective attribute. Indeed ... some reinforcement for the notion that pitch can be analysed into two distinguishable attributes: viz. "height" and "tonality". Appropriately, band-limited noises with different center frequencies might provide an example of sounds that differ in height but have no clearly defined tonality. The

> complex tones studied here, however, represent the opposite extreme; they preserve tonality but evidently cannot be ordered with respect to height."

In an experiment by Korpell (1965) subjects identified single tones which had been re-recorded at speeds different from the originals. By showing that subjects correctly identify the tones according to the new frequencies, Korpell argues that chroma must arise within the ear and not within the overtone structure of the physical stimulus. (But his subjects were of unequal ability and not selected according to AP criteria). Brady (1970) further supports Bachem's definition of genuine AP (v.CHAP.5); and its dependence on chroma recognition is given full support by Stanaway et al. (1970), who present experimental evidence to deny the possibility that their AP subject relates the tones to a single referent such as the tinnitus.

The total breadth of Bachem's contribution may be seen in the fact that a basis is provided within a single scheme for each of the three possibilities for improvement of information transfer acknowledged by Miller (1956) - by referent as in RP, internal referent as in Quasi-AP, or by an increase in dimensionality as in the two-factor theory. Apart from Meyer's rather indignant failure to notice tone-chroma for himself, the only direct criticism of Bachem's phenomenology has come from Ward (1963), who believes that octave confusion arises from stimulus ambiguity when piano tones are used: he does not suggest an origin for the stimulus ambiguity. Ward reminds us that, when Weinert (1929) carefully explained the tonality attribute to his subjects, not one of them agreed that identification depended on the judgment of two components in the way suggested; yet at that time no suitable criteria for AP had been devised to guarantee that these subjects possessed it. (And it emerges below that possessors are often unable to verbalise the nature of their ability anyway).

The present writer, from personal experience of AP - at a level satisfying Bachem's criteria for genuine AP - since his earliest years, was struck by a number of possibilities for its further study. Before acquiring any knowledge of psychology he, as other AP possessors of his acquaintance, took the recognition of tonal quality for granted; a capacity for synaesthesia he also passively assumed to be quite normal. In his own mind the two capacities have been intimately related, each note of the musical scale having its own colour association with the readily identifiable 'chroma' characterising it. It thus comes as a surprise to find that, while several writers (CHAP.2) have suggested this connection, Bachem (1955) specifically disavowed it. In CHAPTER 2, the present knowledge of coloured hearing is reviewed and possible grounds for a link with AP theory discussed.

Chapter Two

COLOURED HEARING

2.1 SYNAESTHESIA.

When sensation becomes interpreted its elements cease to have isolated significance and belong to each other within a global framework. The implications of sensory content are handled as imagery. In its turn, imagery affects future perception and is affected by it: and, when "a stimulus presented in one mode seems to call up imagery of another mode as readily as that of its own" (Vernon,1937), connections between sensation and imagery are manifested in the phenomenon of synaesthesia. Mach's observation (1906) of the analogy in language between tone-sensation and spatial imagery provides an illustration of the complex synaesthetic nexus between auditory stimuli and interacting images of visual and kinetactile sensation. Simpson & McKellar (1955) suggest a convention whereby such manifestations may be classified:

> "Thus the commonest type, visual imagery accompanying auditory sensation, would be termed 'visual-auditory synaesthesia'",

and the image-sense permutations rendered more explicit.

The phenomenon was introduced into psychology by Bleuler & Lehmann (1881) as 'double-sensations', and further discussed by Galton (1883). The actual term 'synaesthesia' was coined by Millet (1892). Early psychological interest was greatly stimulated by the Gestaltist notion of intersensory parallelism - and Kohler (1930) suggested that orthodox scientific thought had over-emphasised the intersense dissimilarities. As an aspect of association itself, however, synaesthesia was recognised by the philosopher, linguist, and musician long before. Aristotle spoke of the 'sensus communis', a "deeper-lying" or supermodal system stimulated by input to the various (five!) senses: (Strong,1891; Reese & Lipsett,1970); and

Locke (1690) in his 'Essay Concerning Human Understanding' refers to a blind patient claiming the most common type of synaesthesia, association of music and colour (= coloured hearing = <u>chromaesthesia</u>). A similar case was reported by Woolhouse, an ophthalmologist c.1700 (Wellek,1931).

The first book on the subject of simultaneous optical and acoustical phenomena was by Castel (1735); and in 1770 Herder suggested that the basis of coloured hearing is emotion. Anologies between sound and light have been explored by artists of both media - Schiller, for example, (1794):

> "we regard every composition in music <u>or</u> words as a form of musical work, and subject it in part to the same laws. From colours too we require harmony, tone, and to a certain extent modulation ..."

- and during the nineteenth century especially (by Goethe, Gautier, Rimbaud, Huysmans, Maupassant). Gautier, quoted by Gibson (1961), writes:

> "mon ouie s'est prodigieusement développée; j'entendais le bruit des couleurs; des sons verts, rouges, bleus, jaunes m'arrivaient par des ondes parfaitement distincts".

Gautier's belief in the close interrelation of all the senses was shared by Baudelaire, who describes his experiences under the effect of hashish (from 'Le Poeme du Haschisch'):

> "Puis arrivent les équivoques, les méprises et les transpositions d'idées. Les sons se revêtent de couleurs, et les couleurs contiennent une musique ... ces analogies revêtent alors une vivacité inaccoutumée ...".

How similar this is to the report by Hofmann (1943) of his discovery of the effects of D-lysergic acid diethalymide (McKellar,1968):

> "All acoustic perceptions, like the noise of a passing car, were translated into visual sensations, so that every tone and noise elicited a correspondingly coloured picture, changing kaleidoscopically in its shape and colour."

That everything visible could be rendered audible, and vice versa, was claimed by Athanasius Kircher 300 years previously: "music ... the ape of light".

Notions of correspondence between music and colour have influenced a number of composers (Handel, Beethoven, Liszt, Berlioz, Wagner, Chopin, Debussy, Franck, Schoenberg, Bliss, Ireland); and elaborate colour-organs have been devised on which, by playing light as well as sound, such imagery may be demonstrated to the public (Scholes,1970). The composer most dramatically dominated by 'tone-vision' throughout his career was Scriabin, who wrote 'Prometheus' ('Poem of Fire') for accompaniment by an ever-shifting visual display (cf. Walt Disney's 'Fantasia'). Experiments continue, and the most recent work of this sort to come to the writer's attention - 'Landscape Journey' by Scavarda - juxtaposes music and "visual plays of fast-moving colours and shapes on two screens" (Kasamets,1964).

Estimates of the <u>incidence of synaesthesia</u> in the general population cover a wide range:- of adults 9 to 16% (Rose,1909; Mudge,1920; Wheeler,1920; P.E.Vernon,1929/30), of young adults and adolescents 16 to 28% (Calkins,1893; Wheeler,1920; Ortmann,1927), and of children 43% (Revesz,1923). The comparatively high incidence of eidetic imagery in children was established as 60% by Jaensch (1930) - in adults 7%; and Argelander (1927) in turn estimates that 40% of eidetics have synaesthesia. In these general contexts all types of synaesthesia are included (number-forms, colour associations with days of the week, etc.); and techniques used to arrive at these estimates have been by no means uniform. Karwoski & Odbert (1938) gave tests in coloured hearing to 274 musicians who claimed not to experience it. They reported that

> "at least 60% of the subjects tested gave some kind of color response to music. Under some circumstances fully 90% have responded colorfully."

And in a follow-up to this study Odbert, Karwoski & Eckerson (1942) report that

> "subjects who are forced to relate colors to music give responses very similar to those of subjects who react readily with vivid visual imagery".

Since the musical stimuli used in these instances were extracts from musical works as a whole it may certainly be argued that the colour responses were to easily recognisable aspects of each composition such as style, mood, or orchestral texture, and that the forced responses may consciously be influenced by common knowledge of the types of association that chromaesthetes experience - indeed the associations of many avowed chromaesthetes might be discarded likewise. Whether we accept such estimates will depend on valid response criteria as well as conditions of stimulus presentation and specification not yet formulated.

Jones (personal communication, 1968) writes of a recent interview with the composer Messiaen:

> "Messiaen said that he believed that all people, when they hear his music, experience the identical perception of colour, even if this is not experienced on a conscious level. This explains some of his more baffling instrumental indications such as 'play red'. He mentioned a friend of his, a painter who was ill, and suffered from the effects of synaesthesia, seeing a colour on hearing sounds. Messiaen stated that he, without being ill, experienced the same phenomenon.
>
> "I was unable to establish if these effects were actual, i.e. hallucinatory, rather than being an inward impression. From the way Messiaen spoke about them, they certainly seemed extremely vivid. He does not have to actually hear music to get this effect, but experiences it - apparently just as vividly - when he reads a score."

This extract raises three of the major questions to be tackled before the mechanisms of synaesthesia may be identified: (1) synaesthesia as a normal vs. psychotic capacity; (2) levels of synaesthetic vividness; and (3) the use of metaphor in synaesthesia. A fourth issue -

levels of specificity in synaesthesia - has received very little attention, and will be considered later in the chapter as the most important aspect of all.

(1) The fact that this phenomenon readily manifests itself in certain schizophrenic illnesses (Jaspers,1963), and in the hallucinogenic state, led to a <u>psychoanalytic view</u> (Hug-Hellmuth, 1912; Pfister,1912; Coriat,1913; Wells,1918/1919; Wellek,1930) of synaesthesia as a symptom of repressed childhood experience. Such opinions were strongly contended by Bleuler, however (1913), who believed synaesthesia to be latent in everyone and consciously experienced by a normal minority. From the 1920's onward the medical interest in synaesthesia waned almost completely: Ostwald (1964) proposes that psychiatrists should take more than their customary notice of the phenomenon when their patients report it, for if the secondary sensations overshadow awareness of the actual stimuli they may indeed indicate mental disorder and provide important clues to its origin.

(2) Luchsinger & Arnold (1965) describe three <u>types of synaesthesia</u>: (a) a 'sensationary' type when the subject claims actually to see colours while hearing music, or, less commonly, when a picture or splash of colour evokes an auditory impression as in a case (AB) investigated by the writer; (b) an 'imaginary' type when the qualities of colour are felt in an abstract sense; and (c) a nominal type "in which the name of a certain color forces its way into the listener's conscience". A similar classification of synaesthetic vividness is suggested by Karwoski & Odbert (1938), who asked their subjects whether

they (a) actually "seemed to see" colour in response to musical items, (b) "associated" colours with the music, or (c) "felt" the colour response in a more intuitive manner. The phenomena of their category (a) will be here defined as '<u>eidetic synaesthesia</u>' since only a few investigators (Morgan,1948; Bartley,1958) have reserved the single term 'synaesthesia' for this type exclusively; that of (b) will be dubbed '<u>associative synaesthesia</u>'; while reports in the (c) category merge indistinctly with those of the phenomenon more appropriately described as

(3) the <u>manifestation of metaphor</u>. Simpson & McKellar (1955) feel it important to distinguish between 'synaesthesia proper' - i.e. the eidetic type - and the 'synaesthetic description', which is the communication of qualities belonging to one sense modality in language appropriate to another. Stevenson (1958) deems synaesthesia a simple product of the poverty of language; thus, instead of seeking specific neurological processes, we should consider the ways in which symbolic reflections of quality from one sense to another are established in the linguistic culture. The correspondences between factors of music and the visual arts in general (Willmann,1944; Stechow, 1953) seem directed by this principle. As Kerr & Pear (1932) state, "the use of simile or metaphor may perhaps be regarded as the entrance door to synaesthesia"; though Merriam (1964) sees the possibility of there being a type of sense-image transfer governed by actual intersensory mechanisms as well as the 'artificial' type of transfer culturally determined.

Essentially, the question is the same as that tackled by the absolute pitch investigator: is there a truly innate basis to the phenomenon? and if so how is it to be distinguished from the environmentally determined variety? As with AP - where at first it seems impossible to ensure that heredity is not involved - so with a case of synaesthesia the problem is to segregate on a rational basis the significantly native experience from those which result from the normal ambiguities of language. The present situation is aptly summarised by Reese & Lipsett (1970):

> "Cross-modal integration seems to have a physiological basis, but the specific mechanisms or processes involved have not yet been identified."!

The first step towards the rational basis for a solution will be to classify the phenomenal content at one time or another subsumed by the general term.

2.2 LEVELS OF THE CHROMAESTHETIC EXPERIENCE.

Synaesthetic content has been amply documented (Whipple,1901; Myers,1911,1914; Langfeld,1923,1926; P.E.Vernon,1929/30; Ortmann,1933; Riggs & Karwoski,1934; Karwoski, Odbert & Osgood,1942; Morgan,1948; McKellar,1957,1968; Simpson & McKellar,1955; Luria,1969). In explaining individual cases the basic search has been for a general logic which may derive from cultural factors, perceptual and judgmental capacities, or from individual idiosyncracies of thought meriting in themselves the depth attention recommended by Ostwald (above). In seeking the basis for a 'true' synaesthesia the economical (not to say parsimonious) theorist will seek general norms for its logic. As was seen earlier, music as a whole comprises numerous factors, and in synaesthesia it joins with a complex of visual experiences which require analysis also.

Karwoski & Odbert (1938) describe the main types of colour response to items of music as follows:

(1) cloud, film or veil effects, billowing vaguely;

(2) spread sheets of colour which may overlap;

(3) pointed or limited colour areas, moving/expanding/contracting with changes in the music;

(4) bands or ribbons of colour developing at various levels of complexity;

(5) patterns of colour gradually filling the field;

(6) meaningful images, which may show some dominant colour or degree of illumination.

In the explanation of normal synaesthesias at this level of abstraction the prime factor that may be identified is mood. The analogous complementary qualities of the colour circle and various mood circles were indicated by Hevner (1936), Luckiesh (1938), and Ross (1938). Noting these, Odbert, Karwoski & Eckerson (1942) reported normal tendencies to associate stimulus music with colours suggesting the same mood (FIG.3b). Though their statistical treatment of the data was minimal, Odbert et al. thus indicate a non-random basis for certain synaesthesias wherein we may observe the need for meaningfulness in the stimulus before a synaesthetic response is likely to occur. The transfer of significant content between modalities is readily apparent in the associative phenomena; while its theoretical nature in 'true' synaesthesia will be discussed once the latter is defined.

Having at this stage identified a global factor of mood on which associations may be based the high incidence among synaesthetes of transfer between vision and audition may be understood in relation to the amount of significant material that the memorised sensations of each modality afford. The varieties of synaesthesia, taken as a complex whole, may be interpreted by their position in a hierarchy denoting <u>specificity of the sensory stimulus</u>. Coloured hearing, in providing more content detail than any other synaesthesia, is a particularly suitable manifestation by which to demonstrate the analysis - quite additional to its special interest in the present context. Each level in the hierarchy is a function of the number of variables comprising the musical stimulus:

(1) <u>music in general stimulating complex response</u>. Composers may add to, or structure, any existing tendencies to a synaesthetic response to their music by deliberately suggesting stories or pictures to accompany it. (La Mer, Pictures at an Exhibition, Vltava, and numerous examples of programme music). In other works they project a general mood (Marche Joyeuse, Marche Slave, etc.), eliciting a corresponding colour association.

(2) <u>Individual determinants of musical mood</u> (cf. CHAP.1) conjure associations in like fashion. Thus the major and minor modes (Heinlein,1928; Hevner,1935), melodic, rhythmic and harmonic variety (Cowles,1935; Hevner,1936), and tempo (Hevner,1937; Rigg,1940) all interact as mood dimensions for the chromaesthetic translation. By an adjective check-list technique - it is unfortunate that the semantic differential, or synaesthetic rating-scales such as those of Schaie (1961) and Lehman (1965), were not then devised - Hevner connected firmness and stability among the musical elements with image qualities of vigour/dignity: smooth modulation of the elements with happy/graceful/dreamy/tender qualities: complexity and dissonance with excitement/agitation/ vigour: and so on (1936). In that factors of musical training, aptitude and intelligence were found to be influential though not essential determinants

of mood sensitivity they are not predicted to have connections with mood translation into synaesthetic terms. Personality measures, on the other hand, may well be involved, in view of the observations that extraverted subjects tend to report more meaningful responses than introverts (Pickell, 1937) - and indeed in view of the extensive links between musical taste and personality forged by Cattell et al. (1954) and Payne (1967).

(3) Each global determinant of mood has its own bases, on which, once they are identified, the rational theoretical framework may be developed. Paradoxically, the clearest and most definite colour responses (Riggs & Karwoski, 1934; Ostwald, 1964) are elicited by simple tones (or vowels) and timbre:

> "The visual sensation begins and ends with the sound itself, and cannot be altered volitionally, by closing one's eyes, or by looking at real colors". (OSTWALD, 1964).

Yet, in the case of associations with single tones, none of the musical elements considered above is present. Hevner's factors of tempo, melodic and rhythmic contrast cease to exist, timbre is presumed held constant, and the only differential stimulus that remains is that of pitch. The specific coloured hearing of pitch is now examined.

2.3 COLOUR AND PITCH.

Reports of the chromaesthetic response to pitch describe one of the richest sources of variation in the imagery literature. In any individual account the pitch stimulus will have been defined - albeit by inference - as either a single tone or as a scalar combination of tones. The representation of tones within a scale does not imply melody, since by definition a melodic structure involves irregularity and flux in the tonal sequence (Meyer,1967). By this very nature melody demands rhythmic flux also (Apel,1964); and, in a scalar structure, rhythm - as the other factors of intensity and tempo - is invariant.

The scalar combination of tones may be simultaneous or consecutive. The smallest interval in Western music, as in the original Pythagorean scale, is the semitone; and the auditory range may thus be divided into a <u>semitonal pitch scale</u>, being that by which musical information is derived from the linear frequency scale examined in CHAPTER 1. Variation along this scale leads to the comparison of one tone and the next in terms of 'tone-height'. Early medieval music featured successive juxtapositions of tone-height alone, with consecutive parts (vocal or instrumental) differing by parallel octaves. The phenomenal nature of consonance, and the partitioning at octave intervals of the semitonal range into 12-note segments, have already been examined: two voices separated by an octave are so consonant as to be indistinguishable unless they are of strikingly different timbres. Our laws of harmonic structure now accept varieties of simultaneous contrast that were once regarded as intolerable dissonances, for the musical ear has learned the information content of simultaneous as well as consecutive tonal contrast, and recognises a wider range of meaningful stimuli to which it may respond. Only recently in musical history (post-Schoenberg) has a system been developed whereby each member of the 12-note scale may occur with equal consecutive emphasis. All cultures select from the available range of notes a relatively small number at a time forming certain modes of expression.

Conventional Western music is based on simultaneous and consecutive contrast in two of the Pythagorean modes, now known as the major and minor keys - further sources of information for the musical ear to extract.

The role of meaningfulness in the synaesthetic stimulus has been argued above. To communicate the 'meaning' of a particular pitch sensation or pitch contrast (its nature revealed in comparison with similar pitch sensations) is a problem even for the musician, who relies heavily on a vocabulary of non-auditory terms including, notably, instrumental 'tone-colour' and (to denote fine variations in pitch) 'chromatic' and 'coloratura' - similarly, the painter speaks of 'tones' such as 'low' and 'high', 'quiet' and 'loud'. To the non-artistic mind such allusions seem fanciful indeed, and, as outpourings of the hyper-imaginative (Harker,1937), they are easily dismissed. Yet on the question of associations with the general pitch dimension there is overwhelming agreement as to a normal trend - the association of low notes with darkness and high notes with brightness (Brentano,1907; Woodworth,1922; Sabaneev, 1929; Zietz,1931; Hornbostel,1931,1935; Ortmann,1933; Riggs & Karwoski,1934; Hartmann,1935; Schiller,1935; Omwake,1940; Werner, 1948; Ostwald,1964; Wicker,1966; Scholes,1970) - hence the adoption of the tonal Brightness attribute by the phenomenologists. The following extract which illustrates the procedure whereby colour associations are apparently attributed to the pitch dimension as appropriate illustrations of the underlying 'brightness' variable, is taken from an account of pitch chromaesthesia in a child of 3½ years:

> "His parents have been careful not to suggest colors to him, and they have not either suggested that a sound may be of a different color from the one he has named. During a few little experiments, the experimenter sometimes said, "I think that color is white", when Edgar had said it was something else. Every time he was very positive that he was right, and he was manifestly disgusted that anyone could think the sound was white when he had said it was red. He often goes to the piano when he is alone in the room, and to amuse himself touches the keys and tells the colors of the sounds. Notes have been made on these colors when he was not aware that he was overheard. Middle-C is red, and the notes just below are red or red-purple. The base is black, and the high notes are white. Between middle-C and the white tones are reddish and bluish tones. Edgar never of his own accord named tones yellow, green or gray; but during some later experiments he found tones for them after seeing the color. One day, upon seeing a rainbow, he exclaimed, "A song, a song!" ....
> (WHITCHURCH,1922).

The additional synaesthetic association of pitch with such dimensions as large-small (Volume), round-pointed, far-near, thick-thin, and so on (Stevens & Davis,1938; Meyer,1967) could have led to an unwieldy number of attributes indeed, had not Boring & Stevens (1936) realised that in the pitch context at least they are synonymous. However divers, these qualities represent a variable that has perceptual significance regardless of musical ability. The attribution of characteristics to different keys is certainly more enigmatic, though by the quantity of anecdotal reports (Helmholtz,1862; Guerney,1880; Colman,1894; Henning,1897; Chalupecky,1904; Myers,1911; Stout,1913; Revesz,1923,1953; Hein,1926; Sabaneev,1929; P.E.Vernon,1929/30; Wellek,1930; Ortmann,1933; Harker,1937; Jeans,1937; M.D.Vernon,1937; Bartholomew,1942; Corso,1957; McKellar,1957; Farnsworth,1958; Carroll & Greenberg,1961; Valentine,1962; Wood,1962; Merriam,1964; Scholes,1970) the key stimulus would appear to provide a more evocative source of synaesthetic association than the single tone; the complexity of typical responses suggests this also. The phenomenon reflects an ancient claim for the existence of key-characteristics; and the following passage expresses the fervour typical of those who report them!

> "The Germans are making a progress in the metaphysics of music, of which we, in this country, have hardly any notion... That much fancy is mixed up in the theory attempted to be established, I have no doubt; but all will admit the difference produced in their sense by two such dissimilar keys as Aflat and A three sharps ...
>
> "Every key is either coloured or uncoloured. The uncoloured keys are expressive of innocence and simplicity. The keys containing flats are characteristic of soft melancholy feelings; while those containing sharps are expressive of uncontrollable and powerful passions.
>
> "C major is quite pure. Its character is innocence, simplicity, naiveté, and the artlessness of childhood.
>
> "A minor represents the cheerful feminine character, gentleness and gaiety.
>
> "F major, pleasure and repose.
>
> "D minor, the melancholy feminine character; the spleen, and the vapours ...
> "F minor, sorrow, funeral lamentations, groans, and sepulchral aspiration ..." (from Harmonicon,1832)

and so on, in all sincerity, through the major and minor keys, twenty-four in all. The Greeks similarly attributed a unique quality, or 'Ethos', to each of their seven modes, naming them after the tribe to whose character the ethos best corresponded. As the harmonic structure of music became increasingly important, the failure of the Pythagorean system to provide certain intervals led to a system of compromise (Wood,1962; Apel,1964) to which the modern keyboard is tuned: in this, the Equal Temperament system, none of the eleven (equitonic) intervals within the octave is as pure as certain of the Pythagorean intervals, though none is unbearably inaccurate ('sharp' or 'flat'). The Greek modes were structurally different, to which fact any associations differentiating them may be attributed; but all keys in modern temperament are theoretically equal: thus, Helmholtz (1862)

> "points out that whatever may have been true of the old modes, the introduction of equal temperament has completely obliterated all differences except the difference of pitch between one major (or minor) key and another". (WOOD,1962);

by which, as will be seen, he does not rule out other bases for a physical difference between them. Kulpe (1901) re-emphasises the point:

> "there is nothing in the whole construction of the musical scale to call attention to the absolute significance of the separate qualities".

And Scholes (1970) concludes:

> "On the whole, it would seem that 'key-colour' is an entirely subjective experience ... part conventional ... partly arbitrary and personal".

Whomes (1895) declared:

> "I have been told my foolish ideas respecting key colour arise from inexperience, that being a young man accounts for my odd views - in fact, I have had enough uncomplimentary and sneering remarks made to cause many men to hide their views from every one".

Similarly, Hadow (1921) records that the harmony tutor to Wagner regarded the youth as idle, that he "would do nothing but talk about the personality of the notes and other fantastic absurdities". Even Beethoven's claim to an association of B minor and black is called into doubt (Scholes,1970): "He often said things on impulse, and we need not attach much importance to chance remarks made by him ..."

The only general tendencies in association that Scholes acknowledges link the flat keys with darker colours, and the sharp keys with brighter colours; these connections he supposes due to a knowledge of the way keys have been used in the repertoire, to an understanding of the sharp/flat composition of the keys, and to the emotional connotations of the words 'sharp' and 'flat'. Though each of these explanations involves a total ambiguity of cause and effect, they may certainly be valid for individuals. Yet we should remember that on the keyboard a 'sharp key' (e.g. Csharp major) may contain precisely the same notes as an enharmonic equivalent notated in flats (e.g. Dflat major). That two physically identical keys may evoke completely different responses from the same individual is a strong argument for the irrational basis of these associations - though observations countering this argument will be reported in CHAPTERS 3 and 4. We may dismiss the hypothesis of Helmholtz that the difference between tonalities is due to the different leverages of the black and white hammer mechanisms by the observation (Jeans, 1937) that on the pianola key-characteristics are remarked though the sound-producing mechanism involves neither hammers nor leverage. Scholes quotes a third theory: that since

> "nearly all the sharp keys have as their third a black projecting key, which may cause the third to be played more loudly; and as the third is the interval that gives brightness, possibly this accounts for (the phenomenon). The reverse is, of course, the case with the flat keys."

But surely this notion would as readily suggest a logical connection of sharp keys and blackness, flat keys and whiteness. And, as Scholes admits, key-colour is purportedly recognised on all instruments, not just the keyboard.

It is curiously intemperate that the modern opinion of coloured hearing should allow the possibility of a logical basis to the association of colour with mood and instrumental timbre, though actively deny one to the associations with keys. Scholes maintains that even the linear pitch associations are groundless; and his main objection to the "false analogy" between sound and colour in general is that the associations of individuals conflict: that even Scriabin and Rimsky-Korsakof, presumably authorities, argued over their responses (red and green respectively) to F major. Yet in the only large-scale comparison of such reports (from 170 out of 250 musical subjects) Sabaneev (1929) claims that certain keys do indeed elicit a degree of unanimity:

> "thus D maj. is described as yellow by 78%, E and B as bluish by 87%, F as red by 70%, G as greyish and brownish by 76%, and the flat minor keys are characterised as gloomy, leaden, dark, or foggy, smoky ...", etc.

In response to these concordances Scholes states that when the letters are ranged from low to high their associated colours do not fall into their order in the spectrum (nor in fact do they range from dark to bright): but he has incorrectly inferred that the associations are with single tones, while, as the original article explains, they are with the major keys. Since music in a particular key ranges over the whole pitch scale and a key-name is octave-recurrent, there is no reason for the colours to fall into spectral or brightness sequence along the pitch scale at all; and, pending a fuller enquiry (CHAP.3) into the logical dimensionality of key-colour associations, judgment on this point should be reserved. Notwithstanding Scholes' misinterpretation, it is surprising that he should dismiss the Sabaneev concordances while quoting as scope for disagreement a calculated 479,001,600 permutations of colour with twelve of the twenty-four keys alone!

In practice, the colour-key phenomenon could prove more amenable to empirical study than the association of colour and simple pitch. By the usual technique of sequential stimulus presentation it may be impossible to tell whether the response to a single tone is based on an absolute judgment or on a judgment of the tone in relation to its precedent. This problem occurs in AP methodology also: the greater the interval between successive tones, the more likely it is that the second tone will be judged as higher or lower than the first, a placing of the tone in its relative position on the pitch scale. Unless one has the patience of Brady (1970) - who convincingly validated his AP ability by judgments of a single tone first thing in the morning for 57 consecutive days - it is unlikely that more than a probabilistic assessment of a tone's isolation may be achieved. In the present study it will be assumed that associations with a single note are ipso facto relative to the note's position in either the tone-height dimension or one of the keys. And in future studies the need may arise to determine whether sequential contrast between the qualities of keys - as they range freely across a uniform pitch range - is of a magnitude likely to influence judgments of them similarly.

A further consideration (Sabaneev, 1929) is that a physically presented note or key may elicit a different colour response from that accorded to the same when it is presented by name in a questionnaire. The <u>association of words and letter-names with colours</u> (exemplified in Rimbaud's 'Voyelles') is discussed by Reichard, Jakobson & Werth (1949) and by Masson (1951), also in most general texts listed above. By Sabaneev it is cited as one of the serious difficulties attending the study of this extremely subtle phenomenon, owing to which "every (methodological) precaution must be taken to avoid mistakes". This, by patient experimentation prior to obtaining the results now quoted, he claims to have done. The 250 persons he studied yield the following incidences of synaesthetic type (and a further reminder of the complexity of response):

- Visual associations of some kind	226
- Definite colour associations	176
- Isolated notes associated with colours	18
- Harmonies associated with colours	24
- Tone-height (Low-High) associated with Brightness (Dark-Bright)	218
- Tonalities associated with colours	170
- Timbres associated with colours	47

Sabaneev's faith in the synaesthetic phenomena is alone sufficient to propel us now to a juxtaposition of the sensory and image capacities accompanying pitch sensation in the light of our present knowledge.

2.4 A TWO-COMPONENT HYPOTHESIS.

From the foregoing evidence it is apparent that a note may be judged in two contexts: (a) in its position on the linear pitch scale, and (b) in relation to a certain key. Many investigators (cited above) have shown the normal synaesthetic association of the pitch scale with a dimension of 'brightness', and Sabaneev (1929) has indicated suggestive degrees of concordance in the chromaesthetic response to individual keys. Any one key contains seven differently named notes, each of which has a specific intervallic relationship with the tonic, thus a unique 'semantic' connotation within the key. As a 'meaningful' stimulus it is thus theoretically capable of a synaesthetic response. According to the scant observations in this respect (Edmonds & Smith, 1923), the synaesthetic response to interval qualities does not differ from one key to the next - this was to be expected since even simple musical form employs a number of different keys in constant modulation. Thus, in practice, the key-related judgment of a single note occurs when the note is the tonic, or 'key-note' to the major or minor key bearing its name.

From the work on AP the hypothetical concepts of 'tone-height' and 'tone-chroma' have developed. Tone-height judgments occur along the linear pitch scale and normally represent an information transfer of 2.3 bits, while the accurate recognition of tone-chroma is thought (above) to combine with that of tone-height to enable pitch-placing in excess of 6 bits, maximum information being derived from the semitonal pitch scale: tone-chroma in Bachem's scheme is a cyclical attribute, octave-recurrent. Thus both AP and coloured hearing have been considered in terms of <u>a two-component hypothesis</u>. A number of investigators have noted claims to both AP and tonal synaesthesia by individual subjects (Stumpf,1883; Abraham,1901; Whipple,1903; Boggs,1907; Revesz,1913; Langfeld,1914; Anschutz,1927; Wellek,1927; Weinert,1929; Sabaneev,1929; Petran,1932), while Kramer (1916) and Booth (personal communication,1971) have each developed methods of musical education featuring the combination of specific notes and colours to aid, it seems, a child's ability to give attention to the notes as individual phenomena rather than relative elements in the musical do-re-mi. Indeed, as Mull (1925), Jeffress (1962) and Sergeant (1967) suggest, early learning of this form of attention may be a critical factor in the acquisition of AP, which would thus rest (Mull,1925)

> "upon an interest in the notes themselves rather than in their melodic or harmonic relationships, which, because of their much greater musical importance, usually monopolize attention."

In France, where the prevailing system of music education and notation emphasises the absolutist nature of notes rather than their relationship with others, the incidence of AP is comparatively high (Deane, personal communication,1971). By the system of tonic sol-fa common in Britain, each member of the scale is notated according to its position in the major key of the moment: thus, in the key of C major, C itself is doh, D is re, E is mi, and so on. In other keys, however, the same notes gain a different name: in D major, D is doh, E is re, and mi is Fsharp. Thus no note is constantly known by one name only. The French system, on the other hand, fixes each note with a single name (C as ut, D as re, E as mi, etc.) regardless of the key in which it occurs at the time, and a reference to the note as an individual entity is thus provided. Experimental support for the notion of absolutist vs. relativist concentration on the notes lies in the report by Brady (1970) of his acquisition of AP by a 'fixed scale' process. By investing each note with the characteristic of its relationship to the key of C major, Brady achieved a level of AP performance satisfying both of Bachem's criteria for the 'genuine' capacity (immediate responses to isolated tones with tone-height contrast thus minimal). His attempt to deduce from this result a general theory of AP based on a 'fixed scale mechanism' relies on the supposition that, when a child, the AP possessor heard music in mostly one key - so that, if the key was C major, G would acquire an identifiable G-chroma characterised by its prevailing 3:2 relationship with C. But Brady's observation that, unlike genuine AP, his fixed scale AP proves incapable of identifying the notes or keys of music in other than C major suggests that the mechanism is of artificial induction similar to the relativist abilities grouped within an

AP heading by Cuddy (1968,1970,1971).

The improvement of pitch-placing accuracy by Cuddy's methods (A-training, series training) is by the development of the capacity for judgment of distances between tones rather than of qualities peculiar to the tones in isolation. Such abilities may certainly be independent of external cues, though, in making direct use of low-to-high information, should be classified as relative (or quasi-Absolute) pitch nonetheless. The recognition of fixed-scale qualities, on the other hand, involves no such reference, and thus an apparent sensitivity to a second level of information consistent with Bachem's description of the 'chroma' dimension. Brady realises that his own two-factor theory is an imperfect one in view of its restricted reliability, but he indicates that "using it, many pieces of the pitch perception puzzle fall into place." Similarly, the current standpoint predicts that a comparison of the phenomenologies of AP and tonal chromaesthesia may provide further clues toward the origin of an 'internal reference scale' capable of identifying all keys and their parts, and to the nature of tone-chroma as proposed by Bachem; for both phenomena indicate a sensitivity to qualities seemingly independent of the normal judgment dimensions.

A preliminary hypothesis evokes the analogy between Brentano's representation of pitch and colour spindle. In each scheme (FIGS.1c, 1d), sensation is composed of a vertical and a horizontal component: visual brightness is the analogue of tone-height, while visual hue corresponds to tone-chroma. At this level of theory a number of pre-scientific attempts have already been made.

> "It must be borne in mind that this domain has long been infected with amateur analogies ... The primitive idea

> usually proceeds on pseudo-scientific lines - sound and light are forms of vibrations, and the pitch of a note is analogous to coloured light ..." (SABANEEV,1929).

In the second century such an analogy was suggested by Ptolemy, and an actual similarity between the breadth of the seven bands in the colour spectrum and the string lengths required to produce the seven different notes of the Pythagorean scale was noted by Newton (1704). Popular objections to the vibration theory have been collected by Scholes (1955,1970): considered together they represent the fact that the objective natures of sound and light are in fact dissimilar. According to Scholes, Newton's original division of the colour spectrum was consciously influenced by knowledge of the musical scale; and Scholes also argues that the behaviour of sounds in combination is completely different from that of colours in combination. Of course, the psychologist is not restricted to considering the physical bases of sensation in his study of the imagery it evokes, so Scholes' points have little cogency. Indeed, at the subjective level, a number of parallels between aspects of visual and auditory sensation have become apparent to the writer during the course of this research: between

(1) colour mixture as legislated by Grassman (1854), and the auditory residue phenomenon (Fletcher,1934,1940; Schouten, 1938 to 1940);

(2) the phenomenon of complimentary colours, and the report of complimentary image fusion by Langfeld (1914);

(3) the negative after-image (complimentary colours), and the auditory negative after-image of Keelen (1967);

(4) the perception of visual flicker, and the sensation of flicker in the chromaesthetic imagery of a subject (DN);

(5) fusion flicker of visual stimuli at critical rates of presentation, and the phenomenon of aural beats;

(6) the extra-spectral colours, and the 'extra-spectral notes' in the imagery of Scriabin (Sabaneev, 1929);

(7) twilight vision, the Purkinje phenomenon, and Bachem's 'photopic' and 'scotopic' hearing;

(8) colour-blindness, and the diplacusis qualitatis reported by Liebermann & Revesz (1914).

The possibility that the normal failure to recognise tone-chroma may be akin to the abnormal condition of monochromatic colour-blindness has already been suggested by Wellek (1927). Criticising this view, Petran (1932) argues that no physiological difference is demonstrated between those who perceive the second component of tone and those who do not. However, more recently Luchsinger & Arnold (1965) have supposed that AP

> "is based on a special anatomic development, principally of the cortical projection of the auditory fibres. It apparently depends on the exceptional supply of ganglion cells for the absolute and discrete recognition of absolute frequency values and their correlation with memory patterns for pure tones."

And in support of such a claim Harrison & Irving (1966) have demonstrated the existence in màmmals of a number of ascending auditory pathways suggesting a two-factor system analogous to the rod and cone pathways in vision.

But Petran has a second objection to Wellek's analogy - that synaesthesia has never been shown to have its probable origin in a mechanism other than random association: this point is as valid today, and highlights the emphasis of CHAPTERS 1 and 2 on the need to establish rational bases for the phenomena. Petran's third

FIG. 3a The Circle of Fifths

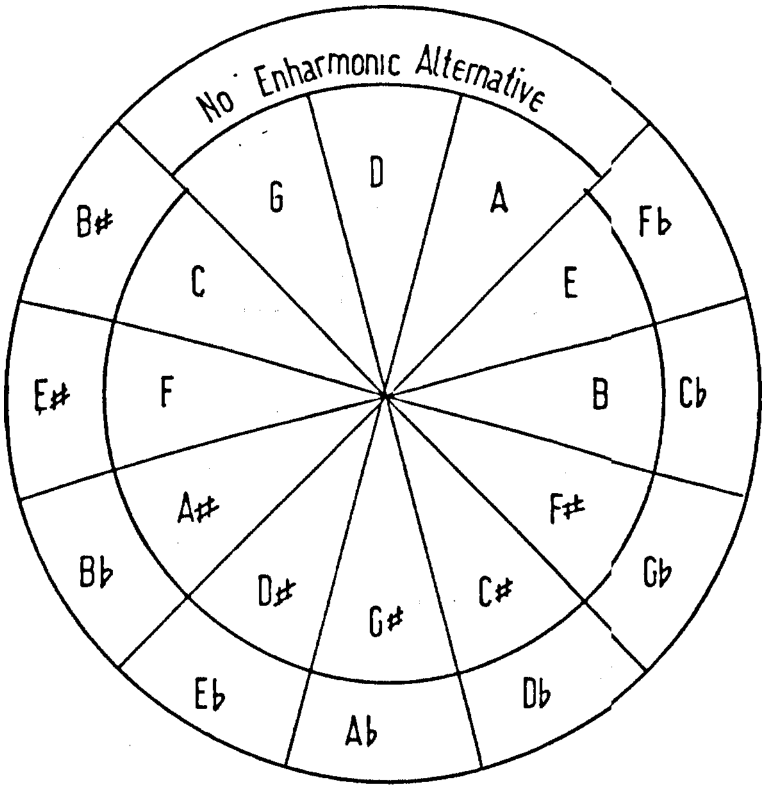
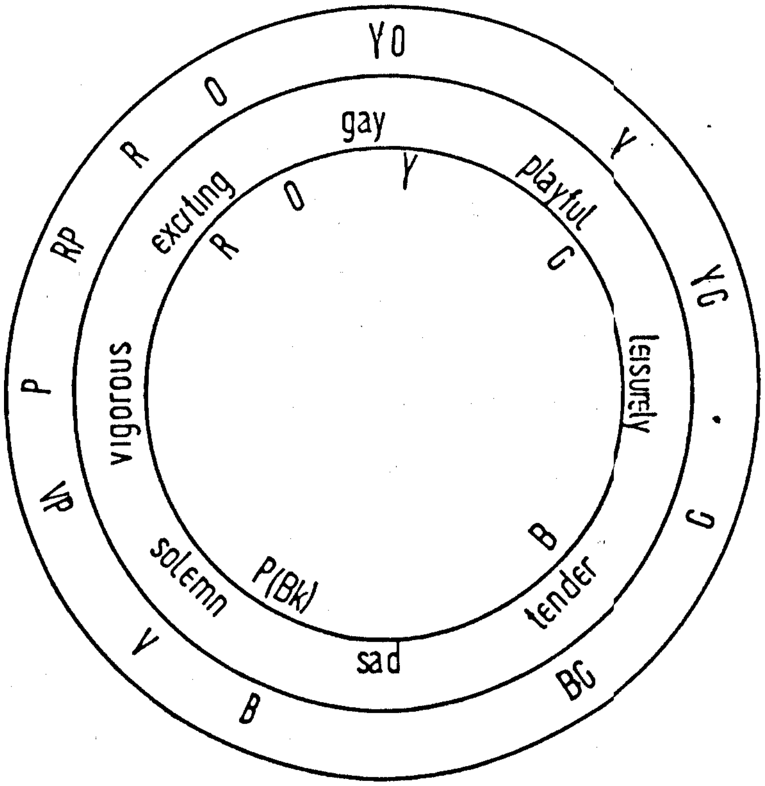


FIG. 3b The Colour-Mood Circle



FIGS. 3 Circular spectra of colour and pitch

argument - equivalent to the fact that colour-blindness and 'chroma-deafness' are improportionally distributed in the population - pays no heed to the fact that the evolutionary roles of colour vision and musical sensitivity are of differing value a priori:

> "Thus, absolute pitch ... appears more as a luxury than a necessity ... after all, music is a luxury anyhow from a biological point of view." (BACHEM,1955).

Thus, it is argued, the highly specific analogies that have been drawn between two-component sensations of both vision and audition point promisingly towards the existence of an underlying rationale from which AP and synaesthesia may both derive. Though Ebbinghaus's criticisms (CHAP.1) of the cycling semitonal sequence implicit in the Drobisch spiral prevent the use of the existing figure as an heuristic model for the two-component hypothesis, a variation of the scheme may overcome each of his objections without any recourse to the complexities of other 'manifold' attempts to do so. For, the spiral ascension may be usefully represented as a sequence of fifths (musical interval 3:2) - a relationship between the musical circle of fifths (FIG.3a) and the spectral colour circle (FIG.3b) was noted in his colour-key associations by Scriabin (Myers,1914). In fact, as Sabaneev reports (1929), the composer originally associated no more than three of the keys with a colour, and the others were established after he had suspected a rationale of this sort. Yet Carroll & Greenberg (1961) - both AP possessors - claim to have recognised the same basic parallel long after their first childhood awareness of the associations. The actual hues of their associations disagree, but the underlying cyclic rationales are similar. The logicality of this connection may be argued as follows:

- the greatest musical consonance between two notes that are named differently, having different chromas (the octave consonance is thus excepted), is that of two notes that are separated by the interval of a fifth;

- the greatest similarity between two colours is that of neighbours on the colour wheel;
- thus the representation of musical notes offering an appropriate analogy to the colour sequence is that in which fifths are adjacent, rather than the semitonal sequence in which adjacent notes provide the greatest dissonance.

In the pilot study (Baggaley,1968) from which the present thesis developed, the associations of 33 chromaesthetes were collated - the study is developed in EXP/B below. In relying solely on the introspective report, the study was of limited value in itself. For example, it was not always possible to differentiate the associations with single notes from those with keys; nor did the associations of a mere 33 individuals lend themselves to an effective statistical analysis for concordance. Yet a number of effects were suggested by the data, and agreement in an individual's associations between segments of the colour circle and the circle of fifths was frequently noted. Only Scriabin, Carroll and Greenberg seem to have realised this parallel, and indeed only Scriabin's associations, prematurely rationalised, yielded a total parallel. The dominant clusters in the pilot data link the flat notes or keys with a progression of dark colours (blue, purple, green) and the sharp notes or keys with reds, yellows, oranges. A sharp/flat dichotomy was also observed in correlations between the general preference ranking of colours and the colour preference order that resulted from the transformation of an observed preference order for the notes/keys into terms of the colours with which they were most frequently associated. It is certainly to be argued that anecdotal evidence of this sort may be an important auxiliary aid to the understanding of a phenomenon, although an efficient theory for the phenomenon must clearly be supported by objective empirical evidence.

The objectives of this work are thus

(1) to pursue in phenomenological terms the two-component analogy between vision and audition as represented by the hypothetical helix;

(2) to determine whether the sequence of consonant fifths serves as a logical basis to the cyclic component of the tonal helix;

(3) to develop an objective empirical technique for the study and validation of effects that the phenomenological data may suggest;

(4) to examine the nature and possible interaction of these effects in AP, and of those linking the visual and auditory modalities in synaesthesia;

(5) to indicate a perceptual rationale on which the phenomena may be based, and

(6) to explore in preliminary form its implications.

Chapter Three

TONAL CHROMAESTHESIA: THE SUBJECTIVE REPORT

EXPERIMENT A.

Introduction: The contention of Scholes (1955,1970) - that colour associations are but arbitrary phenomena differing whimsically from individual to individual - is put to the test. The main hope was for evidence suggesting a systematic relationship between associations and a quality of the pitch stimulus that might prove analogous to the tone-chroma component described above. That individual subjects may associate colours with both of the hypothetical components has already been suggested by the pilot study (cited earlier); though by considering the reports of consciously chromaesthetic subjects alone insufficient data were amassed on the previous occasion for an effective group analysis. In the absence of group rationales for such associations it is impossible to assess or to categorise interactions between associations in individual cases, or to determine whether individual chromaesthesias reflect general or random phenomena. Given that general phenomena are established, the comparison of individual synaesthesias with the generally based rationales should indicate whether, for example, they represent different levels of the same capacity as do the varieties of colour blindness. To test the indication of a general incidence of chromaesthesia (Odbert et al,1942), and in order to create a speedy yet adequate source of association data, the first experiment (A) employed a forced-response technique with subjects not necessarily claiming synaesthetic capacity at all.

Pilot Study A1 - RESPONSE BIAS IN A FORCED-CHOICE TASK.

Method: Following the technique of Omwake (1940) - though using a set of stimuli including each member of the twelve-note scale - a random tonal sequence was presented to individual subjects given the following instructions:

> "You will hear a sequence of 12 sounds, one every 15 seconds, and are asked to write down, by the appropriate number in the scale below, the name of a colour. Some people associate every sound with a specific colour, and even people who do not normally think in these terms can imagine the sort of colour that they would associate with the sounds if they could!
>
> "Whether you normally do or do not think of sounds in this way I am interested to see how you respond to each member of the random sequence that will be presented. (Blacks, whites and shades of grey are allowed as well as the blues, greens, reds and yellows, etc., their mixtures and various degrees of intensity).
>
> "You are asked to rate the clarity/conviction of your response; thus:-
>
> - if the colour association is a vivid one, rate it A
> - if it is only moderately clear, rate the response B
> - if it but a dim, vague association, rate it C
> - if your response is really no more than a guess, put a dash in the rating column (-)
>
> But please give a response, however much of a guess, to each of the 12 stimuli; and remember that there are no 'right' or 'wrong' responses."

A 12 x 12 Latin Square was prepared for the specification of 24 uniquely random sequences each containing the twelve different tones. The stimuli were played on a Steinway upright piano tuned at concert pitch (a^1 = 440 cps) and recorded on a Sony Tapecorder (Type TC-500A) at speed 3.75. Each stimulus was a simultaneous combination of two tones an octave apart, taken from the central 3-octave range between B (key 27) and Bflat (key 62), and allowed to die away completely during the 15 sec. interval between stimuli. Useful comparisons of response to low and high versions of the same tone were envisaged.

The subjects (N=32) were an assortment of musicians, musically inclined psychology students, research workers and teachers aged between 18 and 25 yrs. A casual atmosphere was fostered, not more than three subjects (sitting within 2m. from the Sony speaker) took part at any one time, volume was adjusted to a comfortable level, and each session lasted about 10 mins.

Results: The totals for each confidence rating are presented in TABLE 1. The responses were allocated to the categories (Black, White, Red, Yellow, Green, Blue) to which they best approximated, or were divided equally into categories representing a mixture (e.g. Orange).

TABLE 1.

Distribution of confidence ratings (PS/A1, and Main EXP/A).

	Confidence Ratings			
	A	B	C	(-)
Pilot Study A1	42 = 11%	107 = 28%	119 = 31%	116 = 30%
Main EXP/A	71 = 11%	206 = 33%	184 = 30%	163 = 26%

Despite the subjective element that may occur in the classification by this method of such colours as Brown (allotted here in demi-measure to the Red and Yellow categories), the procedure is thought to suffice for the present exploratory purposes. Disparities were noted between the category totals; these were compared by the Chisquared test for two independent samples with the totals expected by an equal distribution hypothesis (TABLE 2). When the response totals of the four chromatic categories alone are compared with the totals (=77) predicted by the same hypothesis, Chisquared = 4.46, DF = 3, $P < 0.2$ (n.s.). The 6-category distribution is plotted in FIGURE 4a.

TABLE 2.

Observed and predicted totals for Chisquared analysis of the 6 colour response categories (PS/A1).

	Bk	W	R	Y	G	Bl
Obs	44	32	98	75	61	74
Pred	64	64	64	64	64	64

(Chisquared = 23.17; DF = 5; $P < 0.001$).

Discussion: In view of the significant response bias towards Red and against Black, White and Green, this pilot study was discontinued before a stage at which the low and high versions of each note would have numbered equally; so a comparison of the responses to them is not permitted. Neither will the analysis of response agreements to the low and high notes combined be attempted until the nature of bias in this situation has been examined.

If the hypothesis of equal response distribution among the six categories is valid, then the bias may partly be due to the approximations involved in the classification of responses. If one supposes that such bias may relate to colour associations with the timbre of the instrument used, then a simple statistical correction for the bias may perhaps be applied to enable any response factor differentiating the individual notes to emerge. But the central piano timbre is usually associated with a darkish hue, and Red - colour of the present bias - most commonly associated with brass instruments (Scholes,1970). The explanation advanced for the bias to Red is that the responses, being of low conviction (TABLE 1), were distributed according to an unequal set of expectancies related to the number of available synonyms for the six categories, and that 'red' has more synonyms than the rest. This hypothesis is tested in the next study.

Pilot Study A2 - CONTROL OF BIAS BY RESTRICTION OF RESPONSE REPERTOIRE.

Method and Subjects: The indication (CHAP.2) of strong image capacities in children suggested that as an even speedier means to data collection groups of Junior School children might usefully be studied, as by Omwake (1940). The main modifications of Pilot Method A1 was that only one unique sequence of tones could be used at each massed sitting, and that the instructions were rephrased in Junior School language. As Omwake noted, order of presentation affects the quality of a response by contrast, and the sequences failed to counter-balance in this respect. However, at this stage indications of the nature of response bias were the objective rather than evidence for specific audio-visual connections.

An informal study of one 5-yr old boy (ARB) proved encouraging - he expressed no surprise at the idea of a colour response to tones and readily declared the low notes on a piano black and blue, the high ones white, yellow and red. A different random sequence from the tape used in Pilot Study A1 was played to various groups of Junior School children (8 to 11 yrs) ranging in number between 35 and 40. On each occasion the class teacher included the test in a lesson on colour, during which the children thought of as many different colours as they could. Colour responses to a tonal sequence were then required of half the class at a time, while their neighbours were engaged upon other work - this hopefully reduced the possibility of collusion. Each class was tested with a second sequence later in the day without having expected it. To test the synonym hypothesis for the response bias observed above, three separate classes were studied: during the lesson to Class One as many colour names as they could muster were written on the board, while in Class Two (different children) and Class Three (different school) a restricted list of twelve colours and hue-mixtures was written up as follows:

BLACK WHITE
BLUE GREEN ORANGE PURPLE
RED TURQUOISE YELLOW
YELLOWY - GREEN

The study then proceeded as Pilot Study A1.

Results: The colour category totals were compared with their equal expectations as in the previous study (TABLE 3). The observed colour response totals (%) of Pilot Studies A1 and A2 are presented in FIGURES 4.

TABLE 3.

Chisquared analysis of the colour response distributions (PS/A2).

									Chisquared	
		Bk	W	R	Y	G	Bl	Tot	DF=5	DF=3
Class	One	84	98	281	141	96	128	828	76.7*	54.3*
"	Two	110	92	181	160	165	170	876	24.4*	0.7
"	Three	79	65	190	167	139	164	804	54.5*	4.0

(*P < 0.001)

FIG 4a Bias in colour response distributions [EXPS/A and B]

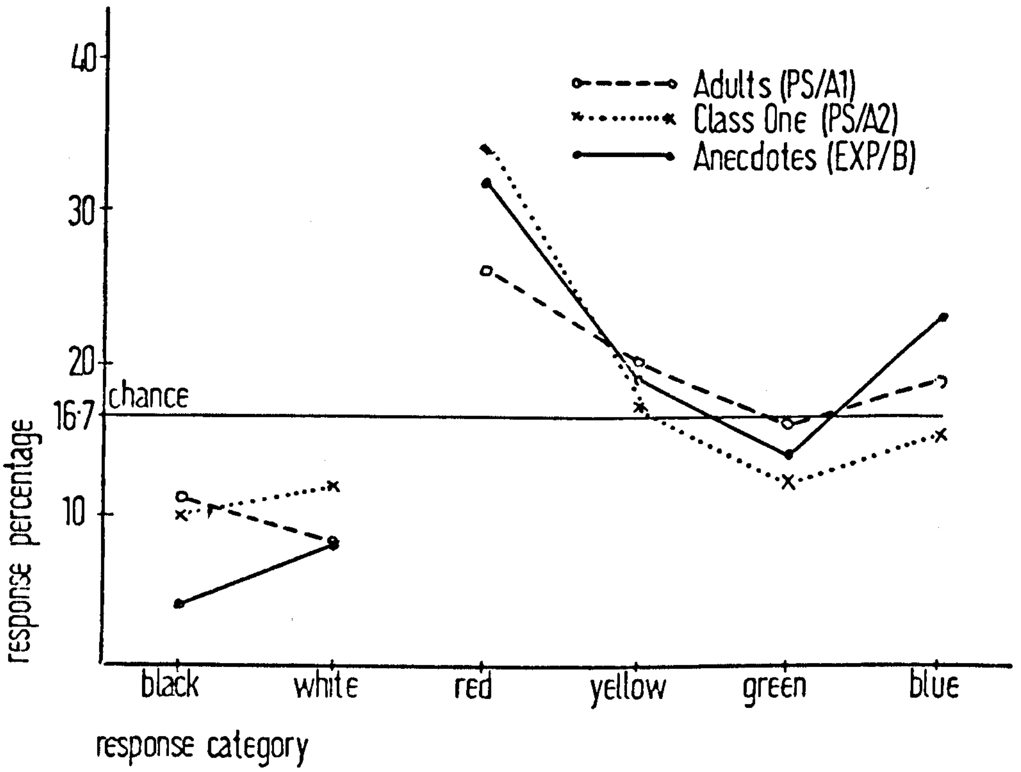
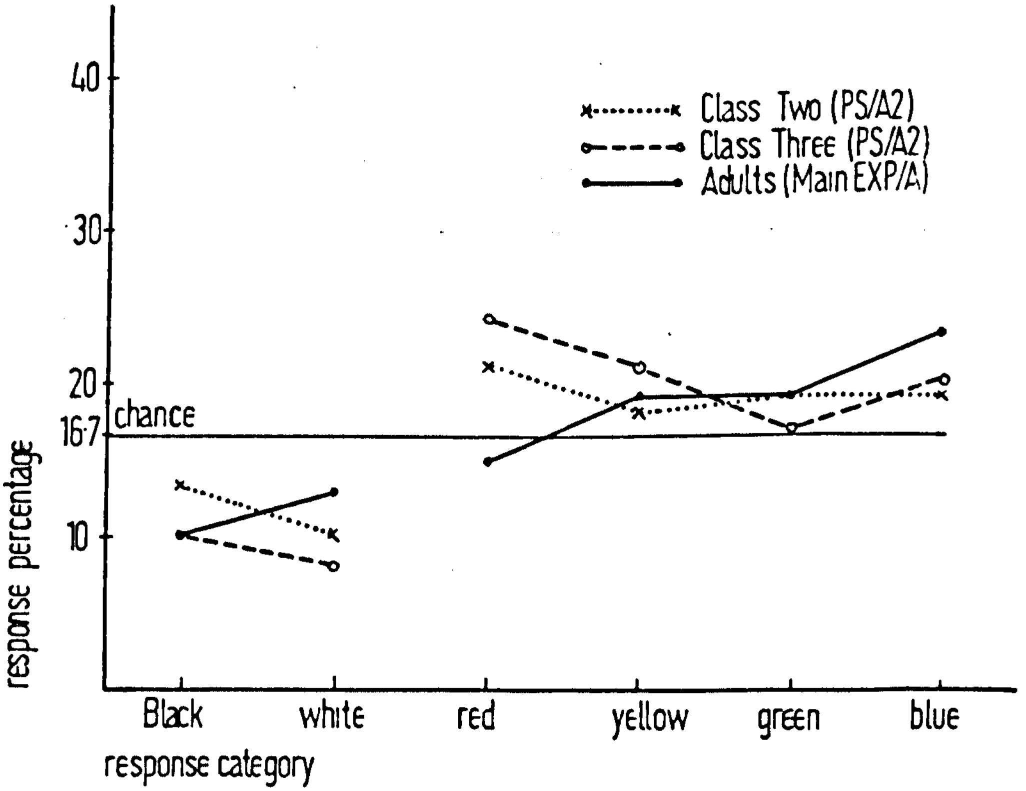


FIG 4b Distributions of colour response where bias controlled [EXP/A]



FIGS. 4 Colour response distributions with and without control of bias

The frequencies (Classes Two and Three) of each type of response to the 12 unique notes were submitted to three-way Analysis of Variance with repeated measures across the factors of (A) Tone, (B) Colour, and (C) Subject groups (TABLE 4).

TABLE 4.

Three-way analysis of variance (PS/A2) across
(A) Tone, (B) Colour, and (C) Classes Two and Three.

Source	DF	S.S.	V.E.	F	P
A	11	12.19	1.11	0.91	(n.s.)
B	5	1531.08	306.22	32.42	< 0.001
AB	55	812.67	14.78	1.07	(n.s.)
C	1	50.17	50.17	3.62	(0.06)
AC	11	13.41	1.22	0.09	(n.s.)
BC	5	47.22	9.44	0.07	(n.s.)
ABC	55	762.19	13.86		

(N.B. F(NonAdd) = 0.676;
after pooling of AC and BC, P(C) = 0.04).

Discussion: The chisquared comparisons, also FIGURES 4, suggest that, although achromatic as well as chromatic responses were permitted, the two types of response category must, in any hypothesis of frequency expectation, be differentiated. The chisquared tests applied to the chromatic response totals alone indicate a bias towards responses of Red in the present study (Class One) as great as that of the previous group (Adults). It is likely that the Adult bias is due to the predominance of synonyms for Red in the general vocabulary, while that of the children (Class One) may be due to the fact that the synonymous colour names were physically displayed to them, with shades of Red in excess. Certainly any significant response bias was eliminated by the imposition of a restricted response repertoire (Classes Two and Three).

Yet the analysis of variance demonstrates, after pooling of the insignificant error terms AC and BC, a significant difference between Classes Two and Three, which - in the absence of a factor to differentiate the children themselves - may relate to the fact that different tonal sequences were used for each. Thus any note may have been presented to the same class in both its low and high versions. If the chromaesthetic responses in this study were to a factor of tone-chroma, it would be predicted that the responses to both versions of a note would be the same. The analysis of variance (TABLE 4) demonstrates that in the group as a whole no significant tonal factor operated: yet it is possible that the combination of low and high versions may have disguised a tendency to respond to tone-height. An estimation of this tendency, by analysis of the responses before pooling of low and high, was not made - for in order that rigorous conclusions might be drawn it would first have been necessary to devise a balanced set of tonal sequences in which each note was presented as both low and high (at least by comparison with the preceding note) an equal number of times. Furthermore, a consecutive contrast of this sort may form an interval that the musical ear can identify as either major or minor; and it was thought likely that a note forming a minor interval with its predecessor might evoke a darker response than that which forms a major interval. (These variables were controlled in the main experiment which follows).

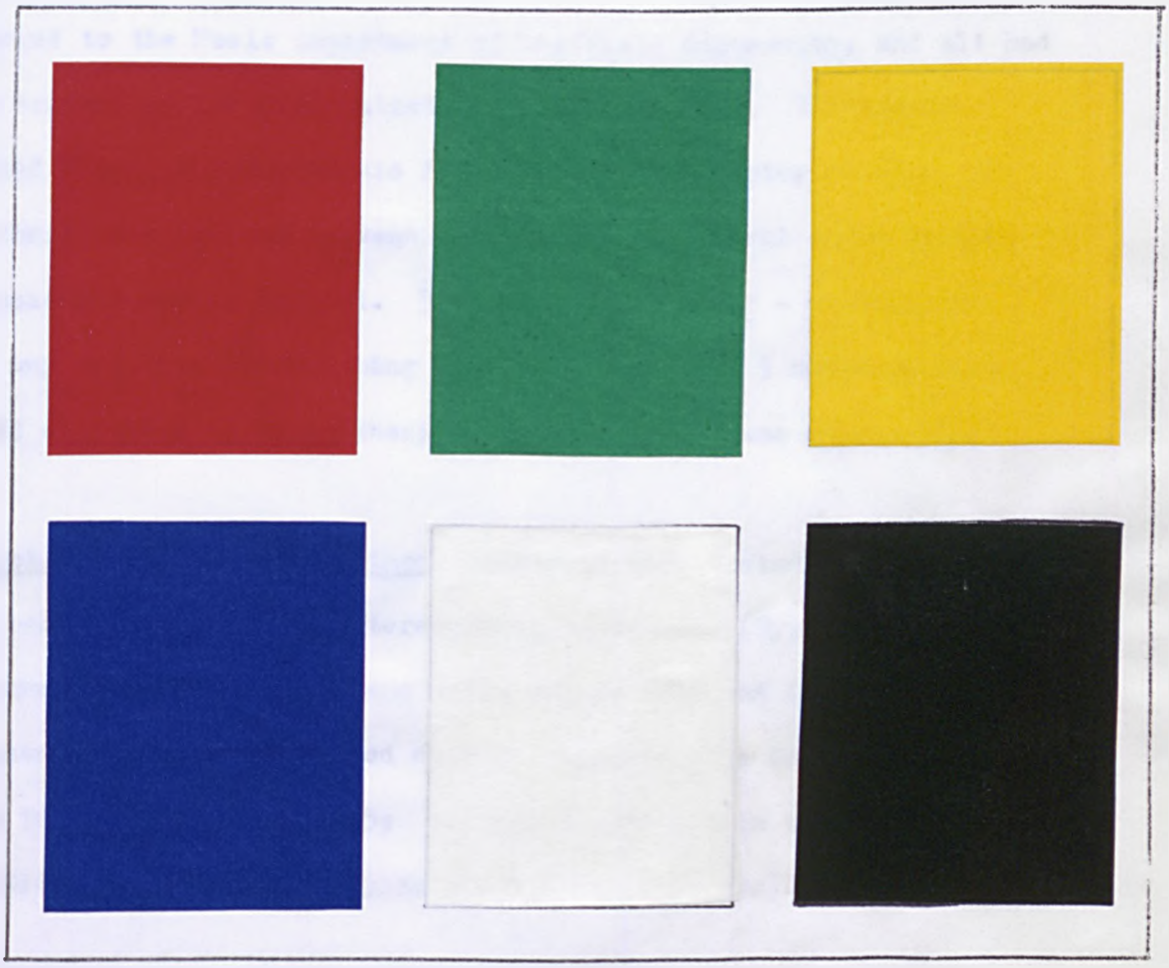


FIG. 5. Random juxtaposition of actual colour repertoire
as presented to one male and one female subject
[Main EXP/A]; to scale 1:2

The prime outcome of the Pilot Studies has been the demonstration of response bias and its elimination in situations where the colours for response are not physically presented: and these observations prove useful in the examination of anecdotal evidence to be discussed in Experiment B.

Main Experiment A - CHROMAESTHETIC RESPONSE TO THE TONE-HEIGHT OF SEQUENTIAL STIMULI.

Subjects: 48 practised musicians, 24 of each sex. The majority belonged to the Music Department of Sheffield University, and all had been trained as instrumentalists for several years. 7 subjects claimed forms of synaesthesia for the individual notes or keys, and 17 others associations between colour and the general style or mood of musical works in general. 5 subjects claimed AP - as distinct from any relative pitch-naming ability - and these 5 numbered among the 24 claimants to synaesthesia. None of the 48 was colour-blind.

Apparatus, Materials and Method: Subjects were tested separately, each receiving over Eagle stereophonic headphones (Type SE-1) a sequence of 13 different piano notes pre-recorded at Concert Pitch (Steinway upright) and played on both channels of a Sony Tapecorder (Type TC-500A) at speed 3.75; all notes were within the octave range from Middle-C (app. 262 cps) to the C above (523 cps).

Set against a grey background 1.5m. in front of the subject's chair was a grey card 30cm. long x 25cm. high: inlaid on cards each 8cm. long x 10cm. high were six colour samples (Butterfly Brand) - the four primaries (Blue, Green, Red and Yellow), Black and White (FIG.5). Illumination was constant from subject to subject. 24 unique tonal sequences were prepared, and each presented to one male and one female subject. The sequences were balanced so that each note was preceded overall by each of the other notes equally: i.e. Middle-C preceded Dflat as many times as D, Eflat, E, F, etc., while Dflat preceded Middle-C as many times as D, Eflat, E, F, and so on through all 156 permutations of the notes used. Similarly, each subject was shown a different display of the colours; all cards appeared next to all other cards the same number of times (=8) in the 48 visual sequences. The <u>instructions</u> were as given in Pilot Study A1.

TABLE 5.

Response frequencies and chisquared analysis of colour distributions (Main EXP/A); <u>N.B.</u> 2 x 2 sub-total crossover.

	Bk	W	R	Y	G	Bl
Bsharp=C/LOW	16	4	9	2	7	10
Csharp=Dflat	18	6	8	1	4	11
D	6	1	8	4	10	19
Dsharp=Eflat	7	2	10	4	12	13
Fflat=E	4	3	4	12	15	10
Esharp=F	2	2	12	8	12	12
Fsharp=Gflat	3	5	10	7	7	16
G	1	6	5	11	14	11
Gsharp=Aflat	3	4	7	10	14	10
A	1	7	4	16	11	9
Asharp=Bflat	2	7	2	15	9	13
Cflat=B	1	19	5	13	4	6
Bsharp=C/HIGH	0	18	8	18	2	2
Total	64	84	92	121	121	142

	Chisquared	DF	P
All colours	20.82	5	< 0.001
Hues alone	5.51	3	(n.s.)

Results: The distribution of confidence ratings is given in TABLE 1. The response frequencies for each colour-tone combination are given in TABLE 5 with the totals (FIG.4a) for each of the six colours as compared with their equal expectations by the Chisquared test. The frequencies of each response to the 13 notes were submitted to one-way Analysis of Variance across the 6 response categories (TABLE 6).

TABLE 6.

One-way analysis of variance across colour response categories (Main EXP/A).

Source	DF	S.S.	V.E.	F	P
Treatments	5	320.46	64.09	2.76	<0.05
Error	72	1671.54	23.22		
Total	77	1992.00			

The fluctuations in response frequency of each colour were analysed for trend across the rising semitonal sequence of 13 notes by the method of orthogonal polynomials (McNemar,1962; Winer,1962): the data were submitted to F-test comparisons with their best-fitting first-degree (linear), second-degree (quadratic), and third-degree (cubic) curves, and the significant fits summarised in TABLE 7, and FIGURE 6. Further Chisquared tests demonstrate that the lowest and highest notes of the range elicit significantly more responses ($P<0.001$) of certain colours (Black or Blue, and White or Yellow respectively) than of others - none of the more central notes does this; but the tests fail to show any significant tendency to respond differently to notes forming a major or minor interval, or according to sex. By Fisher's exact probability test the significance of a number of 2 x 2 'crossovers' conflicting with the general trends of FIGURE 6 were established - e.g. E(Red) = 4, F(Red) = 12, E(Yellow) = 12, F(Yellow) = 8; P=0.03 (cf. TABLE 5).

TABLE 7:

Trend analyses of colour response frequency across the rising sequence of semitones (Main EXP/A).

	Linear			Quadratic		
	(S.S.	F	P)	(S.S.	F	P)
Black	261.121	21.47	<0.001	74.424	2.55	(n.s.)
White	206.791	12.61	<0.01	117.980	4.82	(n.s.)
Red	22.505	3.16	(n.s.)	0.008	0.00	(n.s.)
Yellow	303.434	56.25	<0.0001	0.544	0.02	(n.s.)
Green	7.522	0.40	(n.s.)	133.511	18.07	<0.01
Blue	66.484	5.06	<0.05	50.511	3.46	(n.s.)

Discussion: The significant response trends (FIG.6) indicate a general equation of tone-height with brightness, and support the observation of Odbert et al. that in a synaesthetic response task subjects respond similarly regardless of any prior claim to synaesthetic imagery. Since the tones were all from the central region of the piano keyboard it seems likely that the judgments of tone-height resulted from a comparison of each note and its predecessor: thus Middle-C, the lowest note in the range used, invariably followed a higher note, and elicited the darker colours. Notes in the centre of the range correspond to the peak of the quadratic response curve of mid-bright

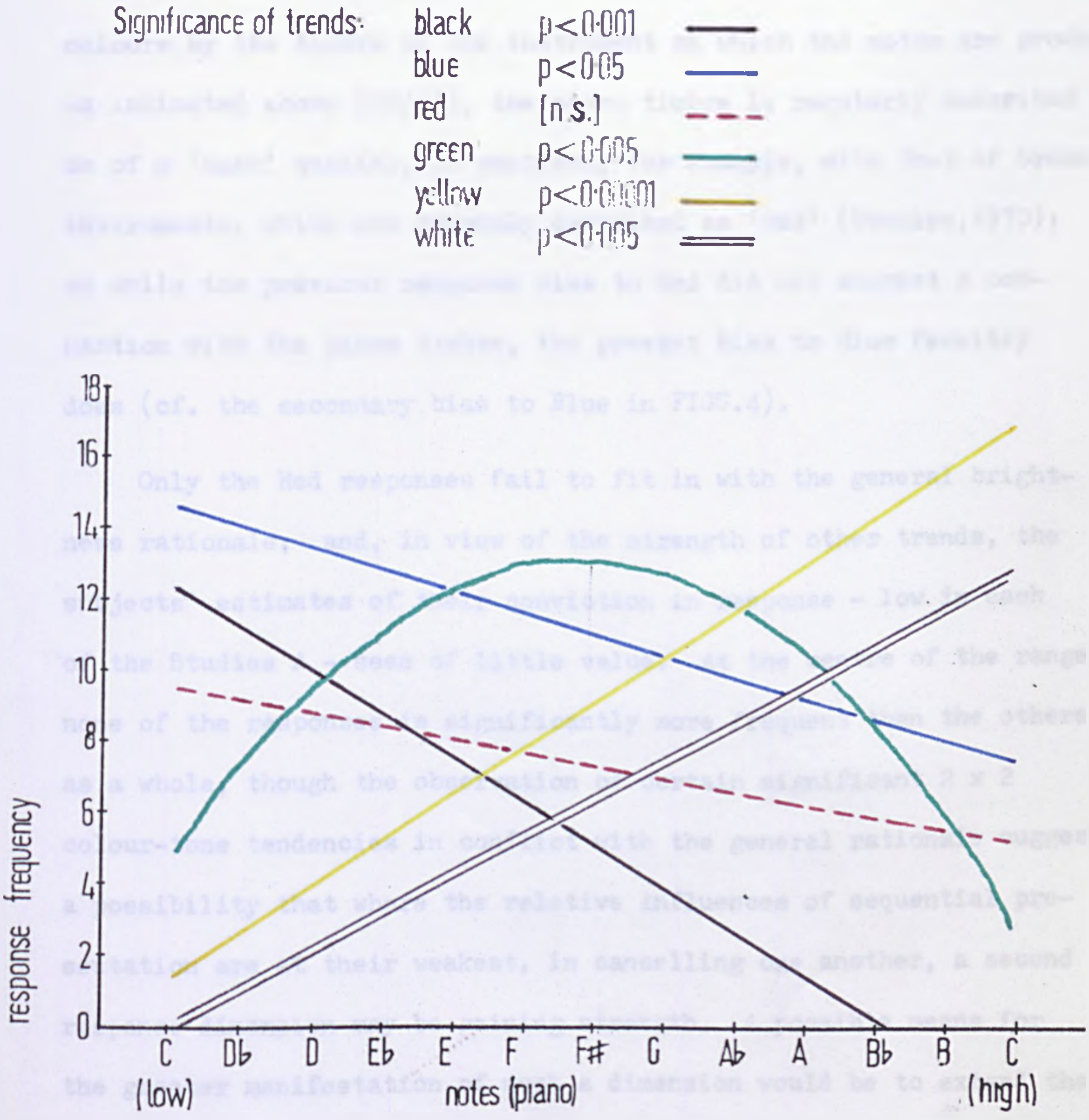


FIG. 6. Best fits to colour response frequency across the rising sequence of semi tones [Main EXP/A]

Green. It is possible that any range of notes would evoke similar responses to these, that the first note in a sequence (or an isolated note) will be judged in relation to its customary (recalled) position of contrast as a low, high or central note in the general range, and that overall response totals may be biased towards various colours by the timbre of the instrument on which the notes are produced. As indicated above (PS/A1), the piano timbre is regularly described as of a 'dark' quality, in contrast, for example, with that of brass instruments, which are commonly described as 'Red' (Scholes,1970); so while the previous response bias to Red did not suggest a connection with the piano timbre, the present bias to Blue feasibly does (cf. the secondary bias to Blue in FIGS.4).

Only the Red responses fail to fit in with the general brightness rationale; and, in view of the strength of other trends, the subjects' estimates of their conviction in response - low in each of the Studies A - seem of little value. At the centre of the range none of the responses is significantly more frequent than the others as a whole, though the observation of certain significant 2 x 2 colour-tone tendencies in conflict with the general rationale suggests a possibility that where the relative influences of sequential presentation are at their weakest, in cancelling one another, a second response dimension may be gaining strength. A possible means for the greater manifestation of such a dimension would be to extend the present tonal range, thereby increasing the number of notes around its centre. But, since this would extend the duration of the task to beyond reasonable limits, it was felt that a technique involving less of the sequential effect discussed here should be pursued in preference (CHAP.4). First, however, in the next experiment, anecdotal evidence is presented for the nature of the second tonal dimension.

EXPERIMENT B - EVIDENCE IN THE CHROMAESTHETIC REPORT FOR A SECOND PITCH QUALITY.

Introduction: It was suggested in CHAPTER 2 that the second dimension of a two-component pitch hypothesis may relate to tonality. By EXPERIMENT A we are assured of the validity of Brentano's vertical component (FIG.1c; tone-height = brightness), and in the present experiment we look for an indication of the basis to the second component. Before the phenomenon may be established experimentally, evidence is sought for normal tendencies in the associations of colour and tonality hitherto reported. It is unfortunate that of the introspective data gathered by Sabaneev (1929) he quotes a selection only; as there is no indication of the criterion underlying this selection, only the associations reported by his Subjects 1 and 2 (Scriabin and Rimsky-Korsakov, also cited by Myers,1914; Farnsworth,1958; Carroll & Greenberg,1961; Merriam,1964; Scholes,1955, 1970) are used in the present study.

The data to be examined here were amassed by the combination of associations quoted in the previous literature with those of cases known to the writer. It was pointed out earlier that colour - tone synaesthetes are frequently unclear as to whether their associations are with the notes or keys. Where they specifically refer to a key, occasional confusion arises as to the distinction between major and minor, though unless it is specified as minor a key may be assumed major in view of the musician's convention for describing major keys by their tonic name alone. In fact, associations with minor keys are mentioned by only a few of the present writer's subjects, and in the present study the major-key concordances alone are examined. Corso (1957) has observed that the absolute identification of tonality depends on the extraction of the tonic (or key-note) from a set of notes tonally related; thus single-note chromaesthesias not relating to the tone-height = brightness rationale are combined with those evidently relating to the keys - our inadequate understanding of the phenomena prior to these experiments made it impossible to distinguish effectively between the various rationales that were suspected. It was hoped that in spite of the variance within associations a main factor of concordance would nonetheless emerge.

Data: were amassed (a) from the following sources:- Colman(1894); Chalupecky(1904); Myers(1911); Langfeld(1914); Hein(1926); Anschutz (1927); P.E.Vernon(1929/30); Wellek(1930); Revesz(1953); Carrol & Greenberg(1961). Care was taken to avoid using more than one report of a single subject. The literary reports were supplemented by (b) the associations of 54 chromaesthetes contacted as a result of advertisements in Sheffield University, in the Musical Times (March, 1967), and on local radio. In toto (a+b) 630 associations were gathered from 80 chromaesthetes, and classified in relation to the six colour categories as in PILOT STUDY A1.

Results (Analysis One): The frequencies of association between each of the 6 colours and 21 tonal categories are given in TABLE 8. Each of the Chisquared tests reported hitherto has shown that the chromatic and achromatic categories should be considered separately. The response totals of each colour category were submitted to Chisquared tests for bias (TABLE 9) as in EXP/A, and the distribution plotted in FIGURE 4. A significant bias to Red is again noted as the inevitable corollary of an anecdotal method. In the previous study, responses - being forced - numbered equally across the six

TABLE 8.

Frequencies of anecdotal association (EXP/B).

	Black	White	Red	Yellow	Green	Blue	TOTAL
C	3.0	24.0	15.0	5.5	3.0	7.5	58.0
(Csharp)	1.5	2.0	10.5	1.0	0.5	2.5	18.0
Dflat	1.5	0.5	12.5	1.0	4.0	8.5	28.0
D	1.5	1.5	15.0	15.0	8.0	13.0	54.0
(Dsharp)	0.0	1.0	4.0	2.0	2.0	2.0	11.0
Eflat	1.0	2.0	12.0	5.5	2.5	12.0	35.0
E	0.5	3.0	15.5	17.5	10.5	8.0	55.0
(Fflat)	0.0	0.0	0.5	1.5	0.5	2.5	5.0
(Esharp)	0.0	0.0	2.0	2.0	1.0	1.0	6.0
F	0.5	3.5	14.5	12.5	14.0	9.0	54.0
Fsharp	2.0	0.0	15.0	5.0	6.0	4.0	32.0
(Gflat)	1.5	0.0	4.0	1.5	3.5	3.5	14.0
G	1.5	2.5	15.0	8.5	15.0	13.5	56.0
(Gsharp)	0.0	0.0	3.5	1.0	3.0	5.5	13.0
Aflat	0.0	1.0	8.5	3.5	5.0	12.0	30.0
A	2.0	5.5	21.5	15.0	4.0	10.0	58.0
(Asharp)	1.0	0.0	3.0	3.0	0.0	2.0	9.0
Bflat	1.5	1.0	12.0	4.5	3.5	11.5	34.0
B	4.0	1.5	12.5	15.0	2.5	10.5	46.0
(Cflat)	1.5	0.5	2.0	0.5	0.0	2.5	7.0
(Bsharp)	0.0	1.0	4.0	1.0	0.0	1.0	7.0
TOTAL	24.5	50.5	202.5	122.0	88.5	142.0	630.0

(<u>N.B.</u> Brackets at right of row totals link response frequencies of enharmonic alternatives (e.g. Esharp and F); brackets around note-names (left-hand column) indicate the less evocative of each enharmonic pair).

TABLE 9.

Chisquared analysis of the colour response distributions (EXP/B).

	Bk	W	R	Y	G	Bl
Obs	25	50	202	122	89	142

	Chisquared	DF	P
All cats	107.53	5	0.000
Hues alone	24.08	3	<0.001

stimulus categories regardless of individual conviction levels. The present study, however, in considering only those associations reported by chromaesthetes (who presumably experience a higher than average level of conviction in these matters) may admit a further source of response bias related to the different evocative strengths of the tonal stimuli. Since certain of the notes/keys are known by two or more different names (enharmonically equivalent) respect was given to each naming in the calculation of response totals for the individual tonal entities. The overall totals for each tone (regardless of response category) were seen to be related to the number of accidentals (i.e. sharps or flats) in the notation of the major key (FIG.7); and from the same figure it is apparent that the technically simpler of any two enharmonic equivalents (e.g. Asharp = Bflat) receives more associations that its more complicated twin. In examination of the subtotals (TABLE 8) for systematic variation, the four chromatic categories alone were taken first.

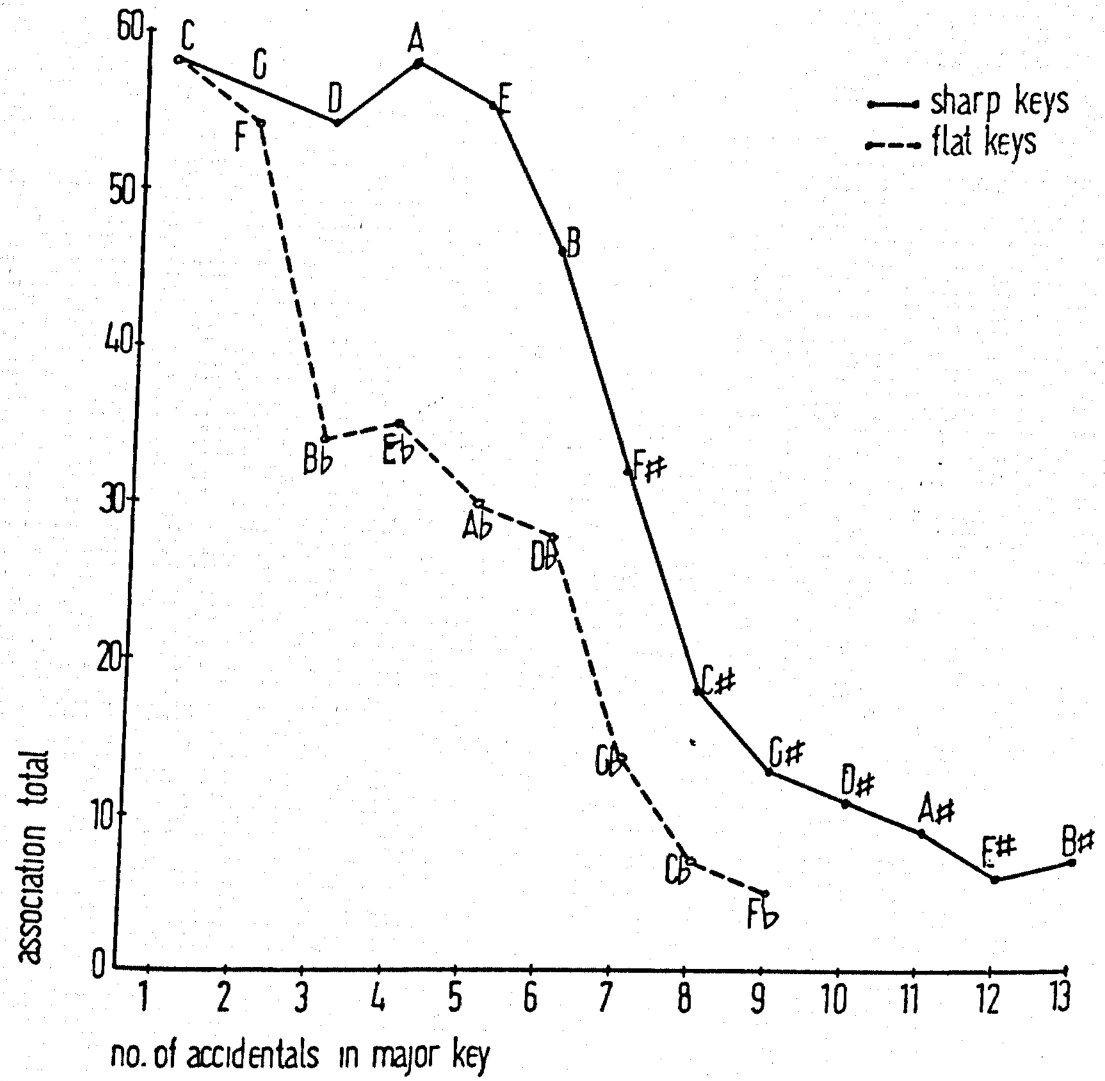


FIG. 7 Simple relationship between association totals [EXP/B] and complexity of major key [cf. FIG. 14]

To correct for the chromatic response bias to Red (accounted for by the colour synonym hypothesis) the scores for each of the four hue categories were transformed into percentages of their category's total; the differences in overall magnitude between each column total (the one-way effect across colours) are thus cancelled, while the note differences within each colour category remain. If the notes and colours are randomly associated, note totals should vary in accord with the hypothesis of tonal familiarity alone (cf. FIG.7). Otherwise, they will vary also in systematic relationship with the colours - and to examine the possible interaction of tones and colours in this two-way effect, we must correct for a one-way effect across the notes in addition to that observed across the colours. Each score was transformed into a percentage of its corresponding row total accordingly. Where C is a percentage score obtained after both of the transformations, the whole manouevre is performed by the single equation

$$C = \frac{25 \times R \times M}{COL \times TON},$$

each response frequency (R) being adjusted in the contexts of its column total (Colours, COL), row total (Tones, TON), and the total across the whole matrix (M).

It is evident from TABLE 8 that the responses to enharmonic equivalents differ - this has already been noted (CHAP.2) and is regarded by Scholes as defying any notion of a general basis to the coloured hearing phenomenon. Having established the <u>principal enharmonic variant</u> of those tones possessing enharmonic equivalents (FIG.7), responses to these variants will be considered first -

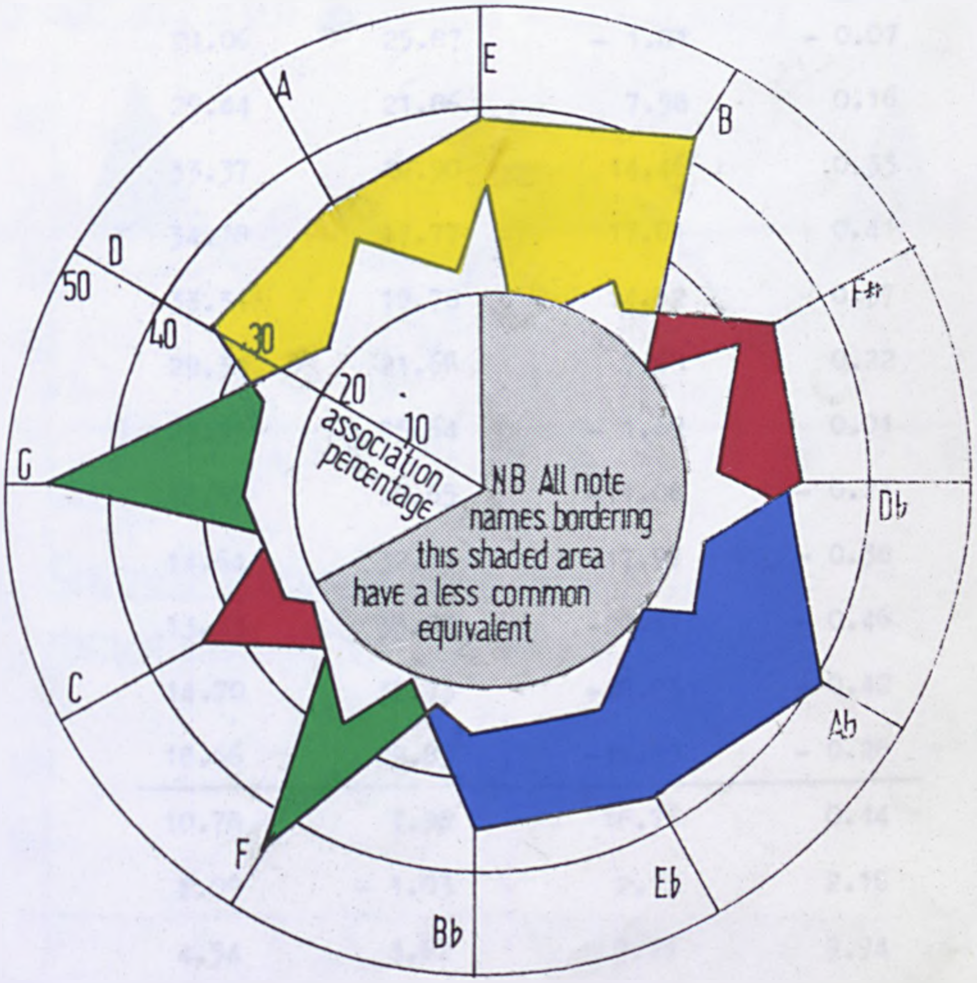
their converted association totals are presented in TABLE 10.

TABLE 10.

Colour association values (%) for the principal enharmonics after correction for bias types (EXP/B; FIGS.8,9).

	Red	Yellow	Green	Blue	(Y-B)	(R+G)	$\frac{(Y-B)}{(R+G)}$
C	33.15	20.18	15.17	23.64	- 3.46	48.32	-0.072
Dflat	32.94	4.37	24.12	31.94	- 6.78	64.98	-0.104
D	20.15	33.45	24.59	24.91	8.54	44.74	0.191
Eflat	25.69	19.55	12.25	36.64	14.43	41.59	0.347
E	20.62	38.65	31.96	15.18	23.47	52.58	0.446
F	19.87	28.43	43.90	17.59	16.79	30.83	0.545
Fsharp	34.26	18.95	31.36	13.03	5.92	65.62	0.090
G	19.76	18.59	45.22	25.37	-27.57	57.06	-0.483
Aflat	20.08	13.73	27.03	40.43	-26.70	47.11	-0.567
A	29.17	33.78	12.42	19.35	-17.09	37.94	-0.450
Bflat	26.10	16.25	17.42	35.67	-19.42	43.52	-0.446
B	21.15	42.12	9.68	25.33	10.84	63.77	0.170

When ordered in linear (semitonal) progression through all the octaves - e.g. from C to B, E to Eflat, Fsharp to F, etc. - no significant linear trend is found (linear regression analysis). However, when the same values are re-ordered according to the sequence of fifths (discussed in CHAPTER 2: Fig. 3a) certain systematic relationships between them emerge (FIG.8). As the sequence of fifths is cyclic, having no finite extremes as does the linear pitch dimension, linear trend analysis is not an appropriate means by which to confirm these relationships. The response



N.B. Values above 25% are above chance level.

FIG.8 Values of association [EXP/B] between the primary hues and the principal enharmonics represented in circular sequence of fifths values of each primary hue were therefore submitted to harmonic analysis (partial Fourier: see APPENDIX IV) across the circle of fifths, and compared by F-test with the 1st harmonics best fitting them.

TABLE 11.

Significant 1st harmonics yielded by harmonic analyses of association values (EXP/B) across the circle of fifths.

	Y	B	(Y-B)	$\frac{(Y-B)}{(R+G)}$
C	24.06	25.87	- 1.81	- 0.07
G	29.44	21.86	7.58	0.16
D	33.37	18.90	14.46	0.33
A	34.78	17.77	17.01	0.41
E	33.31	18.78	14.52	0.37
B	29.34	21.66	7.68	0.22
Fsharp	23.95	25.64	- 1.69	0.01
Dflat	18.57	29.65	-11.08	- 0.21
Aflat	14.64	32.61	-17.97	- 0.38
Eflat	13.23	33.74	-20.51	- 0.46
Bflat	14.70	32.73	-18.03	- 0.42
F	18.66	29.85	-11.19	- 0.28
Amplitude	10.78	7.98	18.76	0.44
Phase	2.09	- 1.03	2.10	2.18
(F)	4.54	3.62	7.21	9.94
P	0.04	(0.07)	0.01	0.005

Results (Analysis Two): F-testing reveals suggestive relationships (after correction for the two forms of response bias hypothesised above) between the 12 principally evocative note-names and the hues Blue and Yellow (FIG.9a). The correspondence between the scores for Yellow

FIG. 9a Yellow and Blue association values [EXP/B]

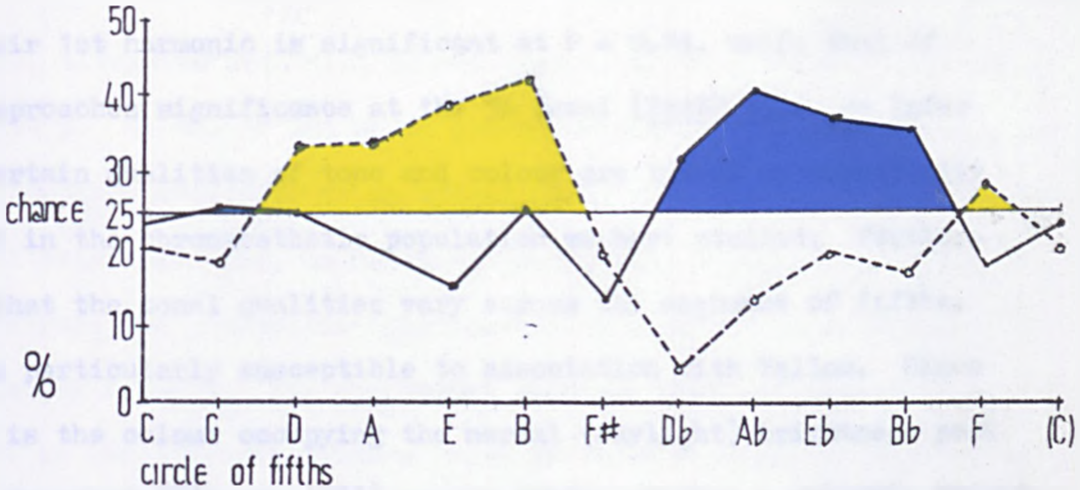


FIG. 9b Red and Green association values [EXP/B]

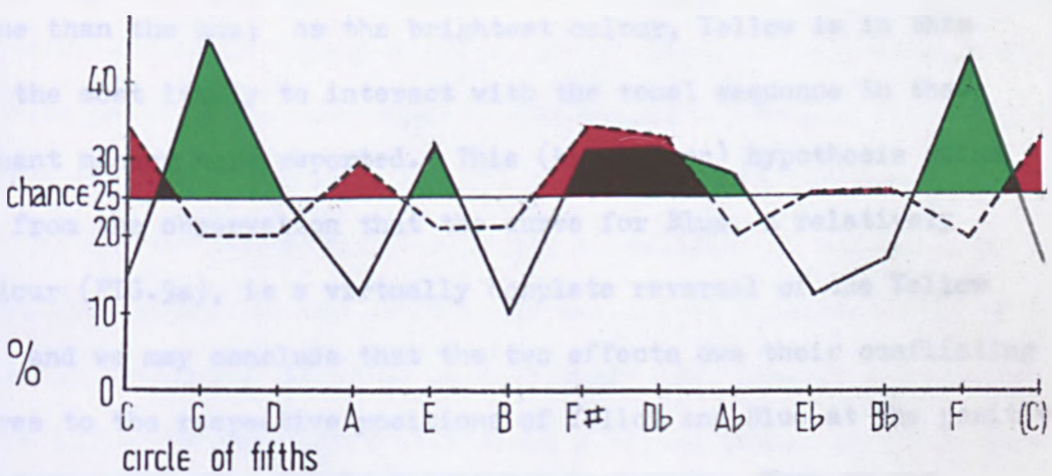
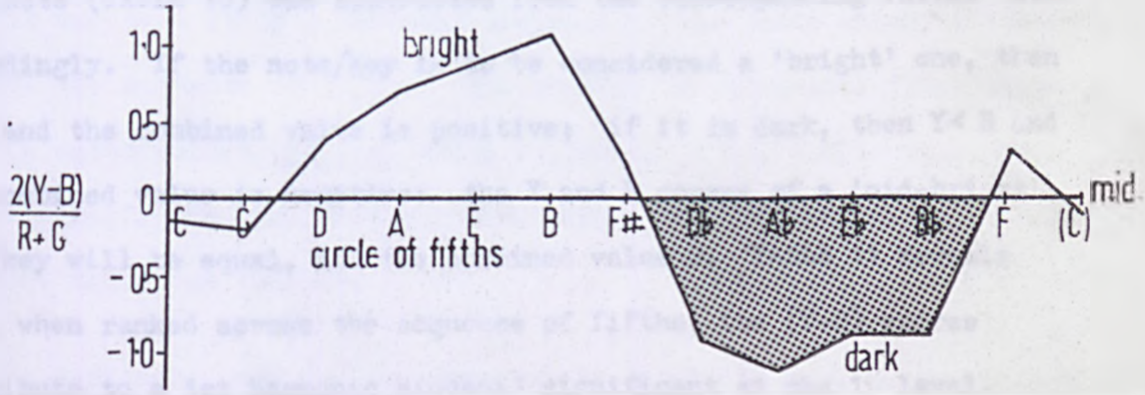


FIG. 9c Sinusoidal brightness curve derived by combination of R,Y,G,B, values [EXP/B]



FIGS. 9 Derivation of the cyclic brightness rationale

and their 1st harmonic is significant at P = 0.04, while that of Blue approaches significance at the 5% level (TABLE 11). We infer that certain qualities of tone and colour are indeed systematically related in the chromaesthetic population we have studied; furthermore, that the tonal qualities vary across the sequence of fifths, and are particularly susceptible to association with Yellow. Since Yellow is the colour occupying the normal (daylight) brightness peak of the spectrum (Stevens,1951) we may wonder whether a colour's brightness characteristic is in fact the greater determinant of its association with tone than the hue; as the brightest colour, Yellow is in this respect the most likely to interact with the tonal sequence in the significant manner here reported. This (brightness) hypothesis gains support from the observation that the curve for Blue, a relatively dark colour (FIG.9a), is a virtually complete reversal of the Yellow effect: and we may conclude that the two effects owe their conflicting structures to the respective positions of Yellow and Blue at the positive and negative poles of a single brightness continuum. Thus we are induced to combine the Blue and Yellow scores to obtain for each note or key a 'brightness estimate'; and the Blue association value for each note (TABLE 10) was subtracted from the corresponding Yellow value accordingly. If the note/key is to be considered a 'bright' one, then Y > B and the combined value is positive; if it is dark, then Y < B and the combined value is negative; the Y and B scores of a 'mid-bright' note/key will be equal, and the combined value 0. TABLE 11 reveals that, when ranked across the sequence of fifths, the (Y-B) scores contribute to a 1st harmonic sinusoid significant at the 1% level.

From FIGURES 8 and 9b it appears that the responses of Red and Green hues are less systematic. Their separate effects, it is to be argued, alternate according to minor association factors discussed in CHAPTER 5. In the effect under present scrutiny they are regarded as contributing additively to an effect (R+G) denoting '<u>mid-brightness</u>' characteristics; and, in order to justify the hypothesis, we must demonstrate the systematic relationship of R and G scores to the values for Y and B. The hypothesis predicts that (1) the combined effect of (R+G) should feature peaks at those sections of the fifths cycle not characterised by extreme brightness/non-brightness, and where (Y-B) is thus zero; conversely (2), a high positive or negative (Y-B) value should accompany a low value for (R+G). For a note or key that is properly to be considered as mid-bright - instance (1) above - the ratio of (Y-B):(R+G) will yield a score which, in being even lower than the corresponding (Y-B) score in relation to other notes or keys, will emphasise and confirm the mid-bright characteristic of the note/key in question. If (R+G) is relatively low, however - predicted instance (2) - the same ratio will yield a higher value, denoting more extreme brightness (positive or negative). Fully stated, the brightness hypothesis thus prompts the assessment of associations between tone and all 4 of the hues in relation to a single sensory continuum; and we may test it by a harmonic analysis of the ratio values (TABLE 11) across the sequence of fifths. The result: a sinusoidal fluctuation of the ratio values (<u>FIG.9c</u>) which is found, at P = 0.005, to be even more significant than previous structures. The brightness hypothesis is thus concluded tenable.

Accordingly, the raw response totals (TABLE 8) have been combined in the three groups (1) Yellow + White, (2) Red + Green, and (3) Blue + Black; thus, we now include the non-chromatic response categories in the analysis. Correcting for possible response bias in the colour and tonal categories, the totals were transformed into percentages as the chromatic data previously. By the subtraction of (3) from (1), a brightness value was obtained for each note as above: the sinusoidal curve formed by these estimates was as FIGURE 9c though interrupted by the value for C, which has received (TABLE 8) an unusually high proportion of White responses: C, in fact, is the only major key containing - on the keyboard - white notes only. On the question of colour associations with the nine secondary enharmonics, no certain conclusions were reached, for on average these notes/keys attract only ten associations each; the main indication by the present data was that the rare note-names (e.g. Asharp, Gflat) most frequently elicit the same association as the note or key bearing the same name (as A or G). In answer to the basic Scholes' assertion that the only system to be observed in such reports is of the flat=dark and sharp=bright variety, FIGURES 8 and 9 demonstrate that the key with the most flats (i.e. Dflat) has in fact fewer associations with the darker colour of blue than with red; while Fsharp, the key with the most sharps, is also associated with red, and not with yellow as the simple equation of sharps and brightness would predict. Or maybe the fact that on the keyboard sharps are black notes nonetheless has disguised this predicted tendency.

In the previous chapter, synaesthesia was considered to be the translation of qualities recognised by one sense into the imagery of another. From the systematic fluctuation of association scores in the present study we may provisionally infer that in addition to the general tone-height form of coloured hearing there is a less common chromaesthesia deriving from a sensitivity to pitch qualities whose variations relate to the circle of fifths. That these are tonality qualities (characteristics of keys rather than of isolated notes) follows from the fact that keys adjacent on the circle of fifths are more similarly composed than are keys related by any other interval. The tonal qualities stimulating both varieties of chromaesthesia are thought to be expressively differentiated in terms of visual brightness for which the hues are subjectively synonymous. And, although associations with the least common (secondary) enharmonics suggest a number of low-level explanations for these phenomena, the cyclic connections between colour and musical pitch indicated by the main effect (FIG.9c) certainly demand a more subtle rationale than is immediately apparent. Of course, the reliance by these data on subjective report, and on an approximating system of classification which makes assumptions about the overall brightness of colours that are not physically presented, prevents any rigorous conclusions at this stage. But the present survey nonetheless provides a valuable stimulus for speculation, and sufficient justification for the development of an objective technique for study of the phenomena in the next chapter.

Chapter Four

OBJECTIVE ANALYSIS OF AUDIO-VISUAL INTERACTION

EXPERIMENT C.

Introduction: When a connection between two heteromodal stimuli is established by a forced-response technique as in EXP/A, it is probably more appropriate to devise for it a term other than 'synaesthetic'. Heteromodal connections have long been established as evidence for the phenomena of intersensory integration, (see London,1954) and these, as will be indicated, have rarely been linked with the phenomenon of synaesthesia from a theoretical point of view. Yet both areas concern transmodal effects, and their failure to combine in systematic research would be more surprising were it not for the absence of observed population tendencies in either phenomenon. The intersensory literature abounds with suggestive tendencies, but no technique has produced objective evidence in this respect, or serves towards classifying the infinity of individual differences that the techniques elicit.

In CHAPTER 3 two rationales for the individual differences in tonal chromaesthesia were hypothetically defined. Relationships between chromaesthetic responses to tone are found on (a) the linear scale of tone-height, and on (b) the cyclic (fifths) sequence underlying musical tonality; and in the present chapter a technique is developed for their further study. In EXP/A it was apparent that a design involving sequential presentation of the tones will elicit the tone-height chromaesthesia alone; and from the vernacular of CHAPTER 1 the term 'relative' is now borrowed to express the distinction between a sequentially stimulated synaesthesia and those which, in being 'absolute', are at least relative to internal standards alone. A design which sought to minimise the effects of sequential tonal stimulation by a direct extension of the EXP/A paradigm would involve much tedium for the subject. If, with the same aim, a restricted number of tones was used, each separated by, for example, a semitone only, the subject would probably recognise the tones by their repeated intervallic relationships (as in Cuddy's studies: 1968,1970,1971); any absolute effect in the subject's responses would thus be confounded. A technique is required which may demonstrate the 'absolute' connections suggested in previous chapters between a quality and each of the notes, across subjects, independent of sequence, and without demanding too much of a subject's time.

An application of the technique described by Holt-Hansen (1968) was considered - his subjects were instructed to adjust an oscillator tone to the position 'of best harmony' with the tastes of certain beers, and the overall harmony between each beer and a particular audio frequency is reported. Unfortunately, Holt-Hansen quotes no detail of his findings' statistical significance. In such a situation the Method of Adjustment is considered - after a few pilot runs by the present writer - to introduce more confounding variables than it controls (the effects of, for example, motor coordination and personality). So, as a possible means of stimulating an absolute synaesthesia hallucinogenically - this supposedly subjugated in most individuals by the dominating responses to tone-height - a sensory deprivation approach was attempted. A dozen volunteers were deprived for periods of between 1½ and 4 hours: with hands bound in stiff woollen mittens, arms and legs strapped in felt lagging material, head encased in a padded egg-box, and ears further muffled by disconnected headphones, each subject was isolated in a totally dark cellar with no idea as to the length of time he would remain there. A microphone hung above him, and, in the event of panic, the subject was permitted to ask for his release. At the beginning and end of each session, the subject's headphones were connected and pure tones presented for his forced colour responses as in EXP/A. But responses gathered in this way held no greater conviction than those of the previous subjects (TABLE 1), and no inter-response system was apparent. Possibly a perceptual isolation situation (Zubek,1969) might have given more profitable results, but the time and money required to test this possibility on a further group of subjects were beyond reasonable limits.

The prediction, following EXP/A, that isolated judgments of tonal stimuli at the extremes of a range may be affected by the recall of their customary tone-height characteristic in relation to the other notes of the range, emphasised the possibilities of a technique developed by Shipley, Coffin & Hadsell (1945), Shipley, Norris & Roberts (1946), Audley & Wallis (1964,1965), and Wallis & Audley (1964), for studying the effects of set on decision time. The early work of Shipley et al. has demonstrated the effect of changed polarity of set on reaction time in judgments of colour preference. Audley and Wallis further indicated that however extreme the stimulus in an overall perceptual dimension, a '<u>cross-over effect</u>' operates in the times taken to make decisions with regard to judgmental sub-dimensions of the task; thus subjects will give a speedier response to, for examples, (a) the brighter than the darker of two relatively bright lights, (b) the darker than the brighter of two dark lights, (c) the higher than the lower of two high tones, and (d) the lower than the higher of two low tones. Marks (1969) has demonstrated the crossover effect in times taken to make subjective judgments of probability: it appears that in the process of a decision initial attention is given to the judgmental alternative suggested by already existing stimuli.

A logical extension of the Audley & Wallis inquiries would, in the light of the tone-height and brightness equation (CHAP.3), be to determine whether a prestimulating low tone will increase the speed of responses to a dull light rather than to a bright light, and vice versa in the several stimulus combinations featuring both modalities and both extremes of the unidimensional stimulus ranges. More relevant to the present investigation, the technique offers a possible means for ratification, in an objective and quantifiable form, of the various types of audio-visual connection that have been suggested earlier. The first pilot trial of the technique's transmodal possibilities probed the 2 x 2 crossover of Red and Yellow observed in response to the notes E and F at the centre of the tonal range used in Main EXP/A (Table 8). If E, the lower note, is indeed connected with Yellow and not with the darker colour Red as the general brightness equation would predict, then one might hope for facilitating effects by E on response times to Yellow, F on Red, and impeding effects between E and Red, F and Yellow.

<u>Pilot Study C1</u> - CONFLICTING COLOUR-TONE INTERACTIONS IN INDIVIDUALS.

(The subject's task was to respond to one of two colour patches, presented tachistoscopically, by depressing one of two response keys as quickly as possible. The position of the colours was varied randomly from left to right in the display field, and, immediately prior to and during each visual presentation, two or three repetitions of a piano note were sounded over the subject's headphones. In subsequent experiments various modifications of this procedure are described; the array of apparatus on which the whole series was conducted is depicted in APPENDIX V, and in the flow-chart, FIGURE 10).

Apparatus and Materials: A continuous two-track tape-loop 8 secs. long was prepared featuring (from a Steinway upright piano) the notes E at app. 330 cps. on one channel, and F at 349 cps. on the other. In a single revolution of the tape were 4 repetitions of each note: each tone lasted 1 sec., and each pair of tones was separated by 1 sec. The tape was recorded and played at speed 3.75 on a Sony Tapecorder (Type TC-500A), and presented to the subject via a pair of S.G. Brown monophonic headphones (Type Super-K) which were connected to the output of the appropriate tape channel as required. The visual display consisted of a grey card 15 cm. long x 10 cm. high, at one side of which was pasted a deeply saturated Red of 2.75 sq. cm., and at the other a comparable square of light Yellow (as in FIGURE 5); the colour samples, as in EXP/A, were selected from the Butterfly Brand set, and were juxtaposed across the centre of the card with a 2.75 cm. margin between them. By inserting the card in opposite directions into the display aperture of a Cambridge (Dodge-type) Tachistoscope, the positions of the two colours were reversed. The subject looked through an aperture 30 cm. from the display; RT's were recorded in 1/100 secs. by circuits between Morse-type keys corresponding to the left and right index

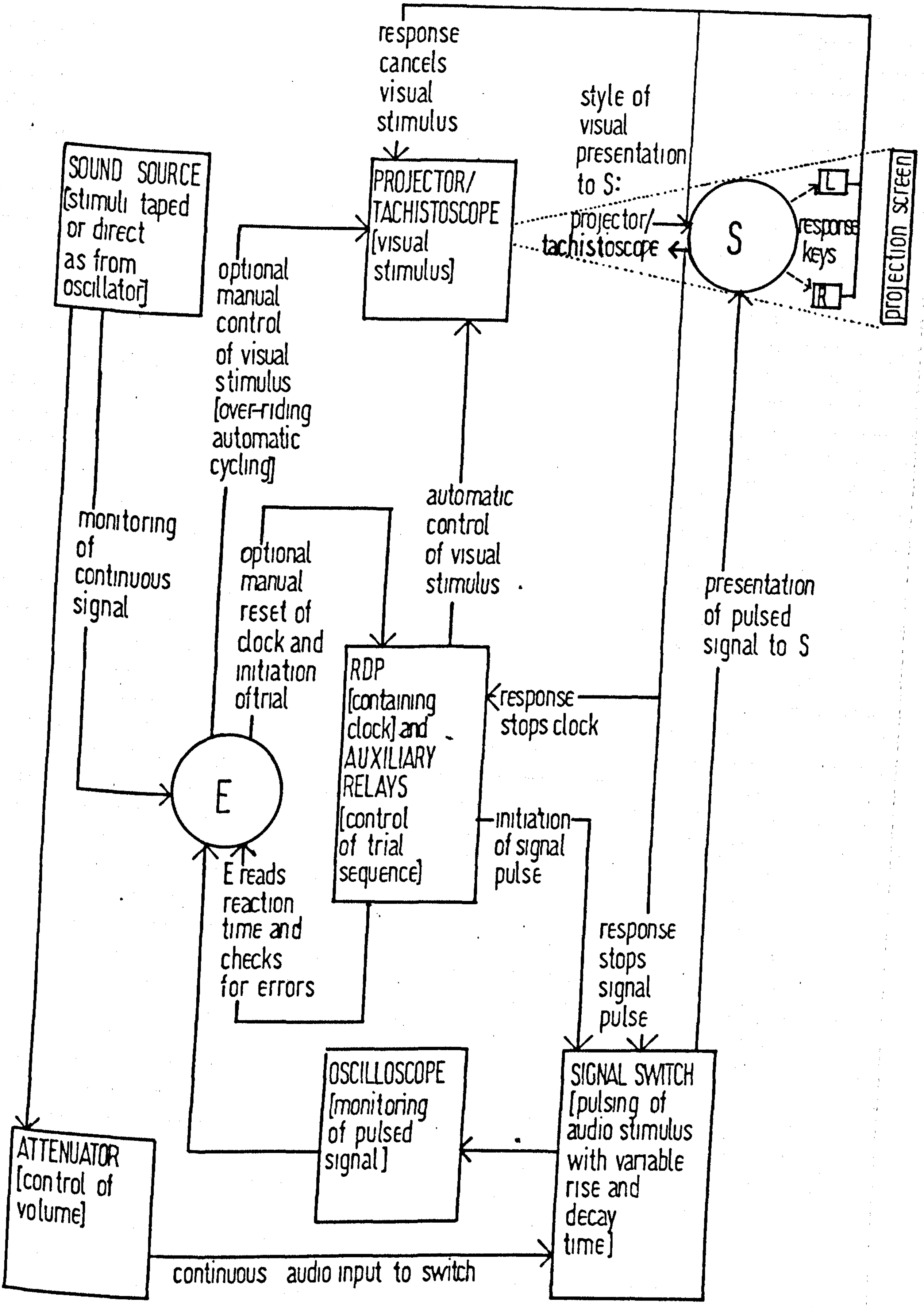


FIG 10 Flow diagram indicating flexible situation of EXPERIMENTS C and D

fingers, and a record of errors was enabled by hold-light circuitry between each key and a 24V bulb; the counter of the RDP Multi-X was wired to control the sequence of each trial.

Method: Before the experiment proper, the subject was requested to adjust the independent volume controls of the tape-recorder's two channels to a comfortable and equivalent level. During each experimental trial S fixated a black 2 x 2 cm. cross at the centre of the pre-field while hearing a random 5 sec. burst from one track of the tape-loop; in any one trial either two notes or portions of three might be heard before the auditory presentation ceased and the visual display appeared - thus any ability to anticipate the appearance of the colours was hopefully diminished; the visual display continued until the subject responded to the position (on the left or right hand sides of the display) of the colour specified by the experimenter as the target for that block of 8 trials.

Eight blocks of 8 trials each were varied for alternate subjects in sequences of (a) RYYR/YRRY, and (b) YRRY/RYYR, each with a pause of app. 3 mins. after the fourth block - possible practice and fatigue effects were thus balanced across conditions. The visual stimuli were varied from one side of the display to the other by a pseudo-random scheme which balanced across conditions for possible handedness effects; the tonal stimuli were varied between E and F (within blocks) by a related scheme ensuring that all stimulus combinations (E-Red, E-Yellow, F-Red, F-Yellow) were presented an equal number of times. Each subject was given 5 practice responses to each colour (without tones); errors in response (wrong key or both at once) were noted and the offending trial repeated later in the block of trials in which it occurred.

Subjects: 8 male and 8 female students qualifying by the criterion of EXP/A as musicians. All had been subjects for the Main EXP/A, though none had been informed of the interaction hypotheses guiding the present experiment. They received the following instructions:

> "Place your index fingers onto the corresponding keys in front of you. Rest your elbows on the arms of the chair. When you look into the machine in front of you, you will see a blank screen with a cross at the centre. The following procedure will be repeated 64 times in 8 blocks of 8 trials each. After a delay not exceeding 5 seconds you will see two colours on the screen, one on the left and the other on the right hand side - in the present experiment the two colours are Red and Yellow. When they appear you are asked to press the key which corresponds to the side on which the specified colour appears (I will specify which of the two it will be prior to each block of 8). Please give your reaction as quickly as you possibly can, but do not try to anticipate the appearance of the colours.
>
> "In order to clarify these instructions I will first give you a few practice trials. At each trial, now as during the experiment proper, the delay preceding the appearance of the colours on the screen will vary randomly. After each trial you will hear me remove the colour-card from the machine; when it has been replaced for the next trial, however, the relative position of the two colours may or may not have changed - their positions vary randomly from side to side.
>
> "Are you ready for the first practice trial? Sit forward with your head in a comfortable position against the viewing-window, and with your index fingers on the keys. As soon as the two colours appear I want you to press the key on the side corresponding to the (RED/YELLOW).
>
> Second practice trial:- this time, as soon as the two colours appear, would you press the key on the side corresponding to the position of the (RED/YELLOW).
>
> Third practice trial:- this time identify the position of the (RED/YELLOW).
>
> Fourth practice trial:- this time the (RED/YELLOW).
>
> "During the experiment proper the colour whose position on the left or right hand of the screen you are to identify will remain constant for at least 8 trials - before each block of

8 trials I shall tell you to which of the two colours you are to respond."

(N.B. The basic procedure for each trial was then repeated and questions about it answered; the statement to subjects that pre-trial lag-time would vary was untrue).

Results: The RT's of each subject (1/100 secs.) were presented for three-way Analysis of Variance. All but one of the 16 subjects were faster overall in response to Red than to Yellow - in fact, the Red made a greater brightness contrast with the light grey background to the display - though only two subjects yielded significant one-way effects of this sort. The main effect sought, an interaction between the R/Y and E/F factors, was again found significant in only two subjects; so there is no indication that such linkage is latent in the general population. Of the two significant colour-tone interactions observed, one (Subject CC; $F=3.97$; $DF=1,72$; $P=0.05$) suggested the facilitation of Yellow responses by E, Red by F (and/or the impedence of Red by E, Yellow by F) while the other (JE; $F=7.94$; $DF=1,72$; $P<0.01$) crossed in the opposite direction, (FIGS.11a, b). An analysis of variance with repeated measures across all 16 subjects evaluated the group tendency to respond to the Red faster than to the Yellow at $F=16.07$ ($DF=1,14$; $P<0.01$), and also confirmed that there was no group tendency to a colour-tone interaction. A few days later the subject (JE) was put through this experiment a second time - the colour-tone interaction (FIG.11c) was on this occasion non-significant ($F=0.04$; $DF=1,72$), and Marks (personal communication, 1969) reports similar losses of effect with practice. Since the direction of JE's original interaction ($P<0.01$) favoured the simple hypothesis of a facilitating link between low notes and dark colours, high and

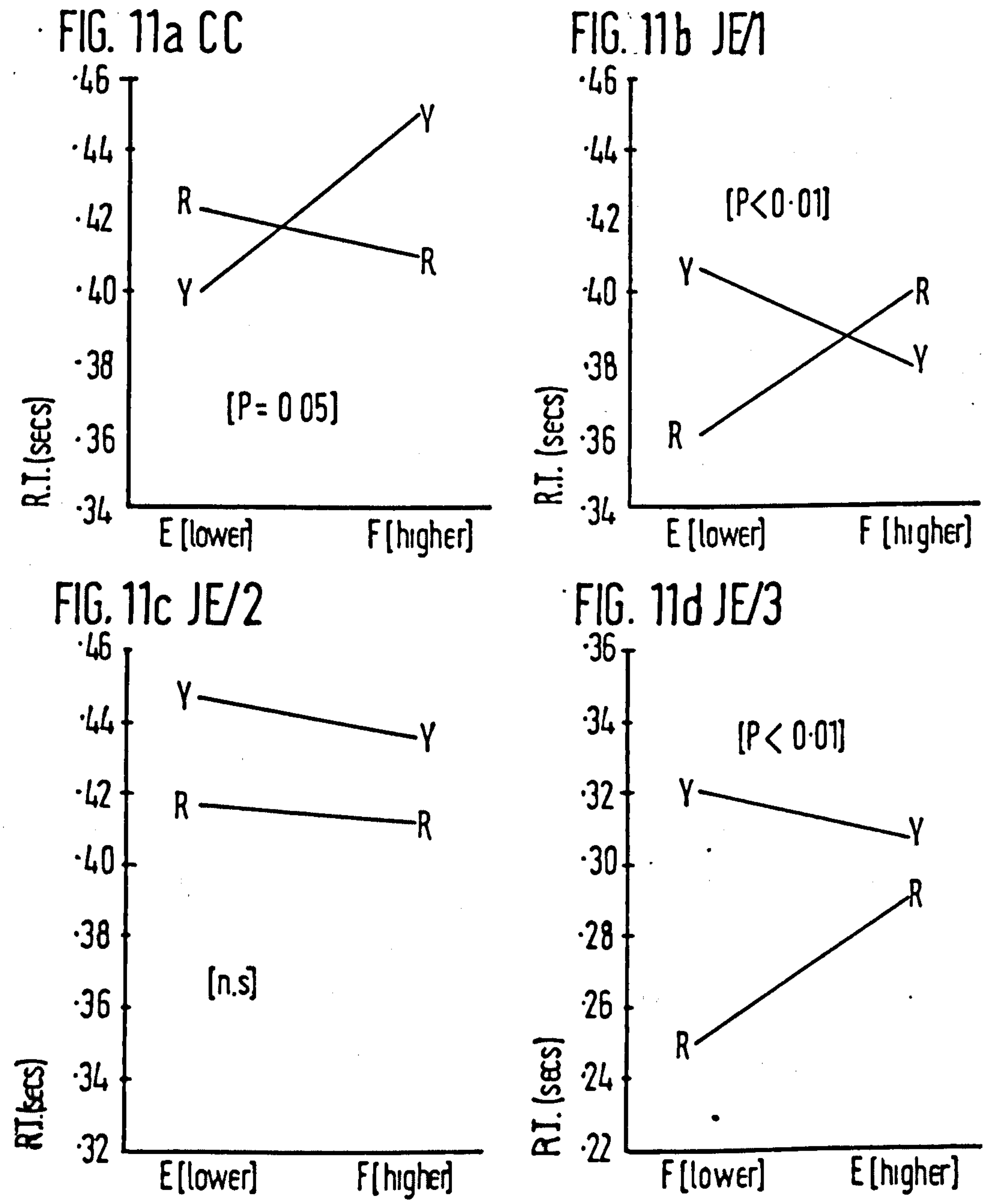


FIG. 11a CC

FIG. 11b JE/1

FIG. 11c JE/2

FIG. 11d JE/3

FIGS 11 Colour-tone interactions of subjects C.C. and J.E. [PS/C1] bright, a further session was conducted a week later in which the E stimulus (330 cps.) was replaced by the E an octave higher (660 cps.): the interval between E and F was thus increased by ten semitones to almost an octave, and the prediction that the F, which stayed the same (349 cps.) and thus became the lower note, would now facilitate responses to Red, the darker colour, was supported in an increased interaction between Colour and Tonal factors ($F=8.15$; $P<0.01$) in the appropriate direction (FIG.11d) - it is evident that the effects of F and Red contribute more to the interaction than do those of the high E and Yellow. It was further apparent that by increasing the interval between tones, the technique might at least prove a useful means of identifying individual tone-height synaesthesias, and, to test this, Pilot Study C2 was conducted.

Pilot Study C2 - FURTHER DIMENSIONS OF COLOUR-TONE INTERACTION.

Apparatus and Method: were identical to that of PS/C1 except that only 32 trials were given (4 blocks of 8 in either RYYR or YRRY sequence balanced across subjects), and with a greater contrast in tone-height provided by a Low E (330 cps.) and High E (660 cps.) recorded from an Airmec Signal Generator (Type 252). (N.B. The calibrations on this equipment were noted by the absolute ear of the writer to be approximately 20 cycles in error, which, at this frequency range, amounts to about ½ tone - the error was verified by comparison with University Music Dept. pianos and an Advance Audio-Frequency Generator (Type H-1), and the calibrations corrected).

Subjects: The tonal contrast to be employed was considered large enough for a possible effect on non-musical subjects; accordingly, and so as not to exhaust the supply of musical subjects at this preliminary stage, 10 non-musicians were studied (5 of each sex), all graduate research students in Psychology; they were instructed as in PS/C1. The subject (JE) who had given useful results in PS/C1 was also examined, though not included in the main group.

Results: Though he was given no indication of the effects that were sought, JE's judgment times once again showed an interaction suggesting a facilitating link between the lower note and the darker colour; the F-ratio for this interaction, however, narrowly missed significance at the 0.05 level (F=4.02; DF=1,32; F(0.05)=4.17), and had it been significant JE's psychological training renders him of doubtful naivety anyway. In the main subject group no significant interaction involving the Tonal factor was observed either at the individual or group levels; the decision to use non-musical subjects was regarded as unfortunate. In order to determine whether interaction tendencies (of which, at a non-significant level, several were suggested) may indeed be connected with musical ability, the 10 subjects were administered, by the specified procedure, the Seashore Measures of Musical Talents (1939 revision, Series A). Estimates were thus obtained of their capacities for discrimination of Pitch, Loudness, Rhythm, Time, Timbre, and Tonal Memory. The (albeit non-significant) F-ratios denoting the colour-tone interaction of each subject were correlated with the Seashore estimates, which, in compliance with the recommendation of the 1960 Manual, were given by the position of each raw total in relation to the population quartiles.

The colour-tone interaction ratios correlated significantly with neither of the tests of Pitch and Tonal Memory as might have been expected (Pearson's r = +0.12 and +0.18 respectively) with the Loudness measure, however, they approached significance at the 0.05 level (Pearson's r = +0.58). If we overlook for a moment the non-significant nature of the F-scores, regarding them as representative of germinal interaction tendencies, we may observe that had they been significant the interactions might indeed have been with the subjective volume differences across the pitch spectrum, noted in CHAPTER 1 though not so far controlled as an experimental variable. Accordingly, the experiment was repeated with the same subjects and procedure but with tonal stimuli now providing a contrast between a Loud E (at app. 65 db) and a Soft E (at app. 55 db.), each at 330 cps. But with the failure once again to observe any significant tonal effect within the RT data two conclusions became apparent. Either the technique was a complete failure, or the predicted interactions are only to be found in musical subjects. The latter possibility is tentatively borne out by the Pilot results of the musical subject (JE), and, for the crucial test of the null hypothesis afforded by the former possibility, 36 subjects were assembled representing three major levels of musical ability.

Main Experiment C - PERSONALITY AND MUSICAL SENSITIVITY IN AUDIO-VISUAL INTERACTION.

Subjects: were categorised in the following way: (1) Non-musical - i.e. no musical training, and with no instrumental ability; (2) Musical - all 1st-Year students of the University Music Department; and (3) Absolute Pitch claimants either known to the writer previously or responding to his advertisements in the University and local Press. Each group contained 12 subjects, and all subjects were required to identify by their musical names half-a-dozen pure tones on the oscillator.

A subject was considered for the purpose of this experiment to possess AP if his identifications were constantly accurate to within a semitone and were not consciously dependent on relative cues.

Apparatus, Materials, and Method: (As in Pilot Study C2, excepting certain modifications). The tonal stimuli now provided a bipolar contrast along each of the three stimulus dimensions considered hitherto (i.e. Tone-Height, Tone-Chroma, and Volume). Four frequency levels were used within the central pitch range: Eflat=311 cps. and A=440 cps. for comparison (as Low notes) with Eflat=622 cps. and A=880 cps. (High notes); these also provided a contrast - independent of tone-height - between the tone-chromata of Eflat and A; while each pair of adjacent tones was separated by the same interval (six semitones, a Diminished 5th). To counteract the differential relationship between frequency and subjective loudness (Fletcher & Munson, 1933), and thus to isolate the experimental factors of frequency and volume one from the other, the oscillator tone was passed through a step attenuator (Advance, Type A64) enabling the correction of each note to the same level of subjective volume across frequencies. The conversion of decibels to phons (the scale of equivalent loudness across pitch) was by a solution of the equation for equal loudness contours given by Robinson & Dadson(1956) - it may be noted that the average age of the present subjects (early twenties) was the same as that of the 1956 subjects on whose data the equation is based: $y_{20}=a+bx+cx^2$, where y_{20} = equivalent loudness in phons, x = sound pressure level in decibels, and a,b, and c are functions of the frequency. The eight stimuli now provided a contrast between Loud

(=70 phons) and Soft (=60 phons) versions of each of the four frequencies. To fragment the continuous output from the oscillator into separate pulses, an audio-switch was purpose-built with variable duration and rise/decay times for each pulse. The selected settings gave a tone of 0.75 secs. including rise time of 50 m/secs. and decay time of 0.1 secs.; and the switch was driven by the RDP Multi-X once a second. The experimenter initiated each trial as in Pilot Studies C1 and C2, and the sequence of events differed only in the fact that the 4 sec. pre-stimulus period always contained four whole pulses, which the experimenter monitored visually on an oscilloscope (Serviscope, Type D31) as well as over headphones (S.G. Brown, Super-K). The phon equivalence from the subject's headphones was checked across frequencies using an Artificial Ear (B & K Labs, Type 4153); and his instructions differed from those previously given (PS/C1 and C2) in that 64 trials were promised. The visual stimuli Red and Yellow remained the same (FIG.5).

After the customary five practice trials (no pre-stimulus) the experment proper was divided into 4 blocks of 16 trials each, with a rest-pause of app. 2 mins. allowed between them. For maximum contrast on the bipolar tone factors of Height, Chroma, and Volume, a sequence was designed in which each pre-stimulus differed from its predecessor on at least two of the three dimensions: thus a Low-Loud-Eflat would probably be followed by a Soft-High-A. This rationale was followed wherever it did not conflict with the methodical progression of stimuli across the four frequencies from low-to-high/high-to-low; the up-down/down-up progressions and, as in PS/C1 and C2, the possible handedness factor in response to the visual stimuli, were balanced across the subjects within each category;

so were the visual target sequences RYYR and YRRY. The whole session including preamble lasted about 25 mins. The situation is reflected in FIGURE 10.

Results (Analysis One): The judgment times of each subject were analysed for variance by a 6-factor design with - for the case of individual subjects - no repeated measures. The five main factors (observations in each cell counting as the sixth) are usefully notated as follows: (A) Tone-Height, low vs. high; (B) Tone-Chroma, Eflat vs. A; (C) Volume, loud vs. soft; (D) Colour, red vs. yellow; and (E) Practice, 1st RYYR or YRRY block vs. 2nd. A one-way interaction (D) denoting greater speed in response to red (as previously) occurred in 30 of the 36 sets of data, and the accentuation of this effect with practice (DE) in 22 out of the 30. Significant interactions of the sort hoped for (AD, BD, CD) were less frequent, there being only one AD (no CD's) in each of the three subject categories (non-musical, musical, Absolute Pitch). In the AP group, however, two significant BD interactions occurred ($DF=1,32$; $F=5.26$, $P<0.05$; and $F=7.92$, $P<0.01$); indeed, the sensitivity to tone-chroma that a significant BD suggests, independent of tone-height, was to be predicted for this group of subjects alone, since previous results have given no indication of latent BD tendencies concordant across non-AP groups. Yet the directions of these two significant BD(AP) interactions conflicted, the first indicating facilitatory connections between Eflat and Red, A and Yellow, and the other the reverse. Of course, each interaction might, by reversal, equally suggest an inhibitory effect, but further observations (this experiment, Analysis Two) suggest that this is not the case. An examination of each subject's raw scores to ascertain the direction of interactions -

whether or not significant at the individual level - showed that in all but one group (each N = 12) the conflicting interactions cancelled out (either 6:6, 7:5, or 8:4), none of these ratios significant binomially. And, as before, no significant group tendency was found in these groups to any of the main two-way interactions AD, BD or CD.

The one exception to these consistently negative findings came, as before, in the case of the BD interactions of the AP group. 10 out of the 12 gave interaction effects favouring a hypothetical facilitation between Eflat and Red, A and Yellow; and this was the effect to be predicted by a comparison of these notes in terms of their brightness characteristics tentatively established in EXP/B (FIG.9c). The two deviant subjects were the only ones also reporting colour associations with these notes in conflict with the norm that the sinusoidal brightness curve suggests. If their scores are omitted on this basis, a group BD tendency is noted suggesting a Red effect in agreement with the prediction that, as the darker colour, it will be facilitated by prior Eflat stimulation - this tendency is significant at the $P=0.03$ level. The raw scores for the group as a whole ($N=12$) were, however, significantly non-additive: $F(\text{NonAdd})= 8.87$; $DF=1,10$: $P<0.05$. So, in this case too, variance analysis on the two main factors of Colour and Tone-Chroma failed to indicate any significant group tendency. It was realised that even the binomial 10:2 ratio linking Red (the darker colour) with Eflat, and Yellow with A, might be due to the position of the two Eflats as on average lower than the two A's. Indeed a separate analysis of variance on the RT's to the higher of the Eflat stimuli and lower of the A's alone yielded an even less significant tendency to a group BD interaction than was noted in the analysis of all the data for BD concordance. So, at this stage, the technique appeared totally unpromising, as by it not one of the group tendencies required in support of the earlier hypotheses (CHAPS.1 to 3) had been established without recourse to the anecdotal evidence (EXP/B) for a basis on which to ignore the deviant AP data.

Theoretical Interlude: A literature search was undertaken with a view to gleaning possible bases for the individual differences that have been observed. In a communication of ideas with Mr. T. Shigehisa (research psychologist at Aberdeen University) the writer was introduced to certain observations that follow from the early studies of intersensory integration by Russian psychologists (Kravkov, Fedorov, Iakovlev, Keksheev, Teplov). Early Western work on sensory interaction (Hornbostel, Hartmann, Schiller, Zietz) was scant though suggestive; since the 1930's only a few investigators (Gilbert,1941; Gregg & Brogden,1952; Symons,1954,1963) have entered the field; and the problems recently studied in the name of intersensory integration - in the information contexts of Bernstein (1969 to 1971), and regarding the coordination of multi-channel information in motor skills (Connolly,1971) - no longer reflect the issues that the heading used to embrace. Indeed, the questions raised in the 1930's, concerning modifications of response in one sense organ by stimulation to another, resemble that of the present study as closely as though they too were originally aimed at explaining synaesthesia. For this reason we should inquire why a truly empirical technique in this field has not already evolved. Certainly, much of the previous work has been of a low standard both experimentally and analytically; and the theoretical work "appears more a collection of eclectic plausibilities than an integrated set of relevant explanations" (London,1954). But these shortcomings do not excuse the present low ebb in this direction, and for its real cause we must look elsewhere.

In one of the scattered Western papers, Howells (1944) demonstrated skilfully that the prior conditioning of one note and red, a second note and green, may lead to a subsequent perception of those colours that is consistently enhanced by the simultaneous presentation of the appropriate notes; and Howell's study is acclaimed by Taylor (1958) as one of "the most important experiments in the history of psychology", implying "that mind is not an independent system with laws of its own, as Descartes believed and as many modern psychologists tend to believe ...". It would be easy, knowing this, to regard all such phenomena in the Pavlovian manner, and the Soviet adhesion to their official dogma probably did more to restrict the intersensory issue than to advance it. Most dangerously of all, it provided a basis on which individual differences cease to have their proper heuristic value; and differentiation of individual subjects into categories illustrative of their various intersensory propensities in experimental situations has been developed no further than the general labels by which the categories are described - 'positive and negative subjects' (Bornstein,1936), and 'integrated and disintegrated subjects' (Jaensch & Mandowsky, quoted in Bornstein). Yet these dichotomies amply suggest the types of differentiation established within the last decade by students of personality, and they may profitably be examined in this light.

From the Pavlovian concepts of excitation and inhibition, and from the mechanistic constructs of Hullian theory, a modern theory of personality was developed by Eysenck. His basis of individual differences on the orthogonal dimensions of Neuroticism and Extraversion (1955,1960) held unbridled sway until the recent accumulation of evidence suggesting (Claridge,1967) that the actual neurological dimensions supposed to underly them may be less independent than Eysenck maintains. The dimensions measured by Eysenck's own questionnaire inventories of personality - the Maudsley and Eysenck P.I.'s (1959 and 1964 respectively) - certainly appear to be orthogonal (or virtually so barring a usual slightly negative relationship) for the scales were constructed on that premise. But in several studies of neurological susceptibilities (Rodnight & Gooch,1963; Savage,1964), perceptual performance (Claridge,1960,1967), and conditioning measures (Taylor,1951; Spence, 1956), complex relationships between the two Eysenckian scales indicate that they imperfectly reflect their neurological substrates. In the context of those performance measures (spiral after-effect, time judgment, vigilance) to which Eysenck typically relates his dimensions (1960,1970), and given the use of the EPI, his chief diagnostic tool to date, certain observations remain valid nonetheless; they engender useful speculations concerning the cortical processes underlying individual performance differences, and an abundance of predictions for further study (Eysenck,1970). We note particularly that introverts tend to over-estimate a stimulus while extraverts, by comparison, underestimate it (these findings are rephrased in Petrie's work on the 'augmenters' and 'reducers' in perceptual tasks). And from the work of

Nebylitsyn, Rozhdestvenskaya & Teplov (1960) we gather that high neuroticism is connected not only with the notion of a 'weak-nerve system' but with higher levels of auditory and visual sensitivity (v.below).

The facilitation of visual sensitivity by simultaneous auditory stimulation was established by Hartmann (1933) and Kravkov (1939), also vice versa by Gregg & Brogden (1952) and Thompson, Voss & Brogden (1958). Serrat & Karwoski (1936) failed to note any facilitation; and the various subject labels for individual difference in susceptibility to intersensory effects have been noted above. The conditions optimally conducive to sensory interaction have been discussed by Bartley (1958), but the reasons for conflict of effects between individuals remain controversial. A partial explanation has been the lack of stimulus uniformity between experiments; for, as Zietz noted (1931), colour quality is influenced differentially by high tones (they make a hue seem brighter than it is) and low tones (darker). But even in this effect individuals differ. In an experiment reflecting that of Zietz, Shigehisa (personal communication,1970) reports that some of his subjects hear a pure pulsed tone (1000 cps.) at threshold level as higher in pitch when they are simultaneously stimulated by red light than when stimulated by green (similarly associated with lower pitch) - but that other subjects report the reverse effects linking high notes with green and low notes with red. (In Shigehisa's experiments it appears that the red is the brighter stimulus, and not as here). Similarly, a green light (for the subjects apparently sensitive to a link between high pitch and red) tends to become reddish-green when pre-stimulation is by high-pitch tones (5000 to 8000 cps.), and red to appear greenish-red on stimulation by low-pitch tones

(300 to 1500 cps.). A number of differences were noted in the performance of introverts and extraverts, the heteromodal stimuli proving more stimulating to the latter and more distracting to the former. Moreover, the two classes of subject - dichotomised by their responses to the MPI - differ in terms of the direction of their intersensory effect: thus, states Shigehisa, intersensory facilitation is associated with the extravert group, and inhibition (a reversal of the facilitation effect) with the introverts. Furthermore, the apparent loudness of 1000 cps. pure tones (20 db. above threshold) is facilitated by a strong green light in neurotics and inhibited in non-neurotics (Chisquared=14.00; $P < 0.001$); while facilitation by weak green light is greater in neurotics than in non-neurotics (Chisquared=6.83; $P < 0.05$). The latter effects operate at supra-threshold levels only.

Results (Analysis Two): With these findings in mind, the EPI questionnaire (Form A) was administered to each of the 36 subjects whose data was treated in Analysis One; all but one subject readily completed it. In the search for bases in Extraversion and Neuroticism for the conflicting interaction tendencies noted above, two measures of interaction strength were used:

- MEASURE ONE (correlations with F-scores): the six-way analyses of variance performed during Analysis One yielded, for each of the 36 subjects, a colour-tone F-ratio on each of the three tonal factors (Height, Chroma, and Volume). In order to determine, firstly, whether the subjects' ratings on either of the EPI scales may relate to the magnitude of their colour-tone interactions, the F-scores for each interaction were correlated (Pearson's r) with the EPI scores

(Neuroticism and Extraversion) across each subject group (N = 12 in each). The results are given in the MEASURE ONE section of TABLE 12.

TABLE 12.

Correlations between measures of colour-tone interaction strength (modulus) and EPI scores for each subject group (Main EXP/C).

		AD		BD		CD		
	No.	N	E	N	E	N	E	
Non-Mus	12	+.436	+.127	+.026	-.131	+.478	-.014	)
Musical	12	+.179	+.007	-.051	+.308	-.121	-.369	) MEASURE ONE
AP	11	+.189	+.173	+.154	-.171	+.765**	-.013	)
Non-Mus	12	+.575*	+.073	+.228	-.101	+.666**	-.041	)
Musical	12	+.149	-.007	-.094	+.463	+.026	-.297	) MEASURE TWO
AP	11	+.264	-.047	+.329	-.087	+.794**	-.203	)

(N.B. AD=Colour/Tone-Height; BD=Colour/Tone-Chroma; CD=Colour/Volume; *denotes $P < 0.05$; ** denotes $P < 0.01$).

Secondly, the four means underlying each colour-tone interaction (on both levels of the two factors involved) were examined for direction of the effect. Where (1) and (2) represent either Low and High, Eflat and A, or Loud and Soft, their two-way interaction with Red and Yellow falls into one of two categories: apparent facilitation of responses to Red by (1), Yellow by (2), or vice versa; (simultaneously: apparent inhibition of Red by (2), Yellow by (1), or vice versa). Each interaction observed during the experiment (funnel, partial funnel, left and right crossovers, etc. - see FIGURES 11) was identified as one of these two directional types by a solution of the term (H-J)+(M-K), where (H) is the mean for the condition Red/1, (J) the mean for Red/2, (K) for Yellow/1, and (M) for Yellow/2. The combination of means in this way yields a value either positive or negative, according to the direction of the two-way effect; and, on adopting the appropriate sign (+ or -), each F-score may be considered on a directional continuum from the extreme of one effect (-) through the point of no effect (0), to the extreme of the other effect (+). The correlation coefficients between the directional F-scores for each group and the group's EPI scores are given in the MEASURE ONE section of TABLE 13.

TABLE 13.

(As TABLE 12, with respect to directional interaction measures).

		AD		BD		CD		
	No.	N	E	N	E	N	E	
Non-Mus	12	-.075	+.284	-.588*	-.111	+.108	-.408	)
Musical	12	+.099	-.103	+.311	-.147	-.285	-.267	) MEASURE ONE
AP	11	-.374	-.352	-.711*	+.129	+.154	-.019	)
Non-Mus	12	-.334	+.241	-.568	-.174	+.342	-.150	)
Musical	12	+.134	-.148	+.279	-.186	-.339	-.192	) MEASURE TWO
AP	11	-.554	-.497	-.720*	+.171	+.242	+.067	)

(N.B. Coding as in TABLE 12; in both tables, No(AP)=11 because one of the twelve subjects was unwilling to complete the EPI).

- MEASURE TWO (correlations with raw mean combinations): As an alternative to the use of F-scores in these computations, the raw (H-J)+(M-K) values for each interaction were similarly correlated with the EPI scores, both as absolute values (modulus, non-directional) and as directional values (the sign heeded). The results (Pearson's r) are given in the MEASURE TWO sections of TABLES 12 and 13.

Of the significant coefficients emerging from this analysis, the two that prove most reliable, occurring under both measures, denote Neuroticism correlations with the Colour/Volume and Colour/Tone-Chroma interactions in the AP group of subjects. The first ($P < 0.01$) is with the modulus (magnitude) values of each measure, suggesting that colour responses of the more neurotic AP subjects are influenced by the Loud-Soft contrast to a greater extent than those of the estimated non-Neurotics: the effect is non-directional - i.e. a Loud note does not have a specific effect on Red or on Yellow exclusively, nor is any such effect differentiated across subjects by the N scores. None of the interactions, as given by its F-ratio, is significant per se (FIG.12a) or enables definite theoretical inference. The correlation ($P < 0.01$) between Neuroticism and the directional measures of Colour/Tone-Chroma interaction (AP group) has a clearer meaning: it indicates that the more neurotic the AP claimant the greater in his response times will be a relationship between colour and tone-chroma that is directed towards the negative interaction type - i.e. a facilitatory link between Eflat and Red, and/or A and Yellow. The reverse of this effect is suggested for non-Neurotic AP claimants; and it is curious that a similar result has achieved significance at the 5% level (MEASURE ONE) in the non-musical group.

At this stage it is unclear whether the effects may derive from facilitatory or inhibitory connections between particular colour-tone pairs: a negative BD interaction type, for example, may be seen as denoting either facilitatory links between Eflat and Red, A and Yellow, or inhibitory links between Eflat and Yellow, A and Red; and the reverse of the effect (positive) may be considered in

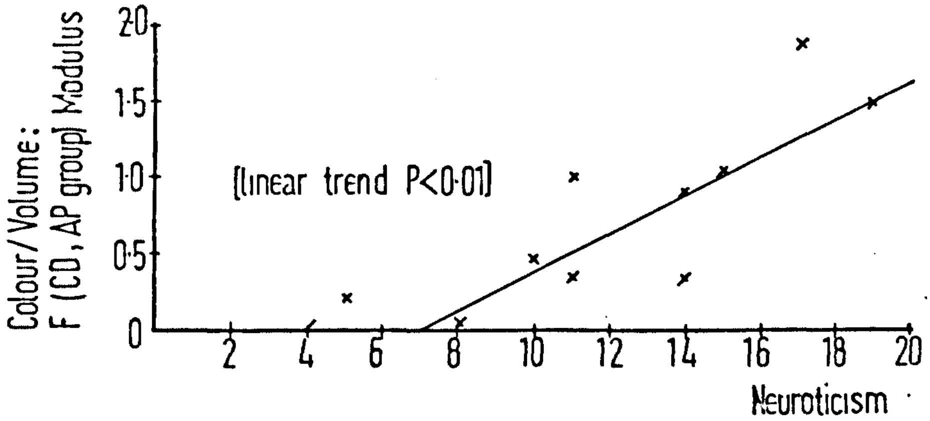


FIG. 12a

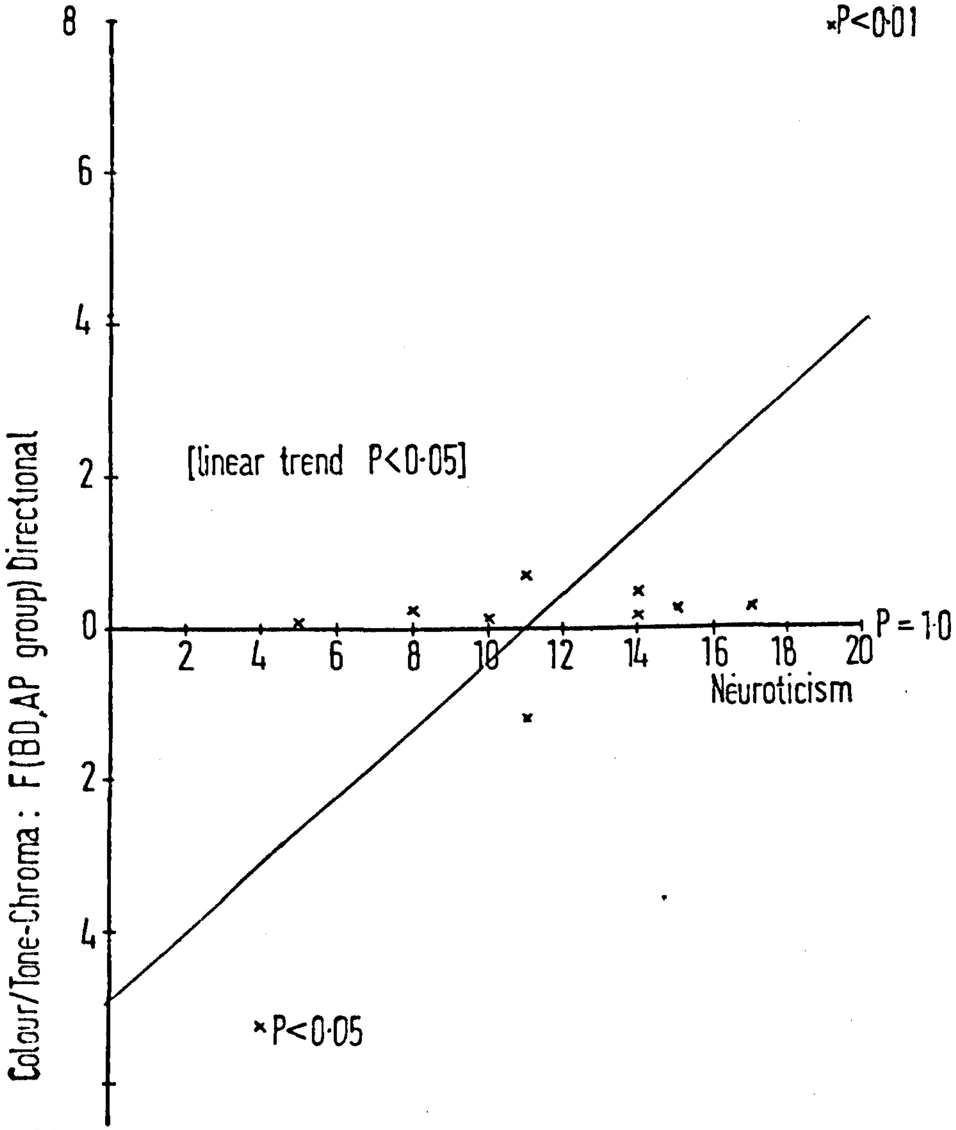


FIG. 12b

FIGS 12 Colour tone interaction strength [F] and Neuroticism in AP subjects [EXP/C] giving significant linear trends.

two ways accordingly. From <u>FIGURE 12b</u> we see that the BD effect is primarily due to the significant results of the two subjects (mentioned in Analysis One) who were in fact the most and the least neurotic of the group. Both of these subjects independently reported colour associations with tonality that support, on the brightness basis of FIGURE 9c, the interpretations that these are facilitatory rather than inhibitory effects. The non-neurotic subject (RP) was one of the only two subjects in the group to associate Eflat major with a bright colour (orange-yellow) rather than a dark one or none at all - RP otherwise describes the key as "noble and broad yet still warm"; and the suggestion is (as in the previous chapter) that Eflat, the single tonic note, is encoded by his absolute ear in terms of the quality associated with the key. The only other subject associating Eflat and Yellow likewise (JH) is seen in FIGURE 12b to give the only other interaction in the same direction; this may indicate - though not significantly - a judgment-time tendency common to both subjects. The more neurotic subject (RB), whose negative-type interaction suggests an Eflat-Red and A-Yellow facilitation, in fact presents one of the most vivid and, for him, imperative cases of tonal chromaesthesia that the writer has encountered; RB describes each of the major keys Eflat and A as Red and Yellow appropriately, and his interaction thus supports the presently developing theory. Of the other nine AP subjects only three report colour-tone associations, though all recognise key-qualities. We may conclude that the preliminary 'screening' procedure on which basis the AP claims were recognised may yet have admitted different levels of the ability within the sample. In CHAPTER 1 the surprising failure of previous investigators to follow

Bachem's lead in differentiating certain levels of AP has already been noted. It may not always be clear whether a claimant bases his accurate judgments on the recognition of a truly absolute quality, or on a simple relative cue; but the present evidence suggests that other levels of the AP capacity may exist even beyond this distinction, and that the Neuroticism scale may usefully differentiate them.

> "From the point of view of the endurance of the cells the weakness of the nervous system" (associated with high neuroticism)" is a negative property ... Such a viewpoint appears almost self-evident. Pavlov himself adhered to it, characterizing the weak type of nervous system as a "more or less invalid" type. This viewpoint, however seems to us one-sided and consequently erroneous (and certain) facts and theoretical propositions, which we expounded elsewhere (Teplov,1956), have led us to the hypothesis that <u>the weakness of the nervous system is internally connected</u> with its high reactivity, or high sensitivity."
>
> (NEBYLITSYN et al.,1960)

Nebylitsyn's hypothesis leads us to the prediction that the more neurotic an AP claimant, the more pronounced his sensitivity to tone-chromal qualities, and the more revealing his colour-tone interactions in a task such as that reported here. It was thus decided that in the selection of subjects for the next experiment (D) an appropriate battery of tests should be administered in order that the subjects with higher levels of AP sensitivity might be identified and further conclusions with respect to the accompanying audio-visual interactions be made possible.

EXPERIMENT D.

Introduction: Having ascertained that for certain subjects tonal stimuli may exert a significant influence upon judgments of colour, a primary question is whether the effects will operate in reverse. In the individual cases so far reported two dimensions of stimulus influence have been identified, corresponding to the tonal components of Height and Chroma hypothesised in CHAPTER 2: it is significant that effects involving the former dimension occurred in the response times of Non-AP musicians, while those of the latter were given by the RT's of AP claimants alone. But the stimulus repertoires so far used have been limited to a bipolar visual contrast between Red and Yellow, and, in the tone-chroma factor to a contrast between Eflat and A. It is probable - and, assuming the validity of the systematic relationship found between associations in EXP/B, positively to be expected - that Eflat, for example, may interact with a Green or Blue to a greater degree than with the Red or Yellow, while the latter two may combine to greater effect with other notes. An interaction between colour and tone-height seems to occur whatever the tonal range and independent of tone-chroma (EXP/A); in AP subjects, however, the chroma effect is theoretically independent of tone-height. Only by featuring all twelve of the chromata in the experimental stimulus repertoire will the extents of the possible interaction system be determined; and only by pairing the chromata with the four primary colours at least (R,Y,G,B) are the differential interactions between them likely to indicate whether the underlying rationale is one of hue or brightness.

In order to obtain the objective evidence required in the latter respect two methods of approach are available: firstly, we might prepare visual stimuli in which the hues differ while brightness and saturation are held constant, and if no effects on response time are noted proceed to vary the brightness and saturation of a single hue stimulus in order to establish whether either of these exerts an influence. Colour samples enabling fine specification of these dimensions, based on the Munsell (1929) and Ostwald (1931) systems, may be obtained in time and at cost; but even when different hues are equivalent on all other physical dimensions it is unlikely that they are identical subjectively: for colours have their own affective stereotypes (Birren,1961; Aaronson,1968,1970). The specification of colour may yet develop to an ultimate in sophistication, expressing all colorimetric dimensions to which the eye is sensitive, and the architects have already suggested a fourth dimension arising from the inequalities of brightness gradation across hues (BRS and RIBA committees,1969); but in psychological work the subjective assessments of each stimulus in terms of its customary relationships to other stimuli may yet involve numerous dimensions more important still. Moreover, the supply of AP possessors is too valuable to be expended in the preliminary experiments that this approach would necessitate. The other approach (that which was actually taken: below) incorporated both main variables (hue and brightness) in a single design as the factors of Height, Chroma, and Volume were combined in the previous experiment. The colour stimuli of EXPS/B and C embodied both dimensions at once, and without due forethought the two might certainly be confounded; in the present experiment, however, we may provisionally identify a brightness effect by its trend across the linear pitch scale from low to high, and an effect of tone-chroma by its relationship to the tonality scale (circle of fifths) described in CHAPTERS 1 to 3.

Accordingly, a judgment task was designed enabling, for AP subjects, judgments of individual tone-chroma, and which members of a Non-AP control group would also be able to perform. Additionally, by treating tones as the judgment stimuli and visual stimuli as the hetermodal variable (the reverse of EXP/C) an answer to the reciprocity question may be provided.

Criteria for Selection of Subjects (PRELIMINARY to Main EXP/D).

A battery of Pitch tests was prepared, that claims to AP might be verified: it was administered individually to 45 subjects of all ages claiming musical ability: the sample included 17 of the writer's AP contacts. The sequence of tests was recorded and played at speed 3.75 on the Sony TC-500A as follows:

(1) A random sequence of 12 piano notes (Fsharp, B, Dflat, E,A,F, Aflat, D, Bflat, C, G, Eflat) from the tape used in PILOT STUDY A1. Subjects were instructed to identify each note by name and when in doubt to guess. The response lags (unknown to S) were timed in secs. on a stop-watch, and, if a judgment took longer than the 15 secs. following each stimulus, the next tone was delayed until the judgment had been made. Two possible measures of AP capacity were thus provided - Accuracy (and extent of error in semitones) and Judgment Immediacy, the measure indicated in CHAPTER 1 as being important in the classification of AP and its RP imitations.

(2) The Seashore measure of Pitch discrimination (1939 revision, Series A, instructions as per 1960 Manual);

(3) The Seashore measure of Tonal Memory (detecting a change of

note in phrases of 3,4, or 5 notes; ref. as 2);

(4) The Wing test of Memory (detecting a change of note in a short melody: Wing,1960);

(5) The Wing test of Pitch Change (detecting a change of note in a repeated chord; ref. as 4);

(6) A random sequence of pure tones for identification as in (1) above; the tones were recorded from the Airmec Signal Generator (Type 252), after checking, by the method of beats (Wood,1962), that their frequencies agreed with those of the University Music Dept. Steinway upright piano tuned at concert pitch (A = 440 cps.) and with the Advance Audio-Frequency Generator (Type H-1) similarly employed in PILOT STUDY C2: the calibrations of the Advance A.F.G. were compared with the piano notes and with the frequency values given in the Table for the Twelve-Note Tempered scale by Revesz (1953); the method of beats, by which these calibrations were found accurate to within 1 cps., provides a fine means of extending the accuracy of A.F.G. settings in the absence of a precision digital gauge. The sequence of tones was as follows (cps. in parentheses): Dflat(554), Bflat(466), E(330), D(294), Fsharp(370), Eflat(311), B(494), Aflat(415), F(349), G(392), C(523), A(440); each note lasted 5 secs. and the interval between notes was 20 secs.

Random (chance-level) accuracy on tests 2 to 5 was calculated at 47/140 = 34%; the only non-musical subject tested (CM: she claimed to be 'tone-deaf') scored 49/140 on these measures (=35%) thus effectively validating her claim. The scores of the 45 musical subjects ranged between 105/140 (=75%) and 138/140; on the basis of their accuracy in piano-pitch identification (Test 1) the subjects were divided into four groups. The first group embraces the lowest levels of performance with a total of correct identifications between 0 and 3; the second group contained subjects scoring from 4 to 6, the third those scoring 7 to 9, and the fourth 10 to 12 (=100% correct). The totals of correct responses in tests 2 to 5 were analysed for variance in a one-way design (no repeated measures) across the four unequal groups; the difference between them was not significant (F=2.12; DF=3,43). The procedure was repeated with the scores denoting accuracy in pure-tone identification (Test 6) - this time the effect across groups (F=2.96; DF=3,43) was significant at the 0.05 level. The means for each group in response to both piano and pure tones are given in FIGURE 13a. The piano/pure scores of the 45 subjects correlated at the 0.001 level (Pearson's r=+0.657; N=45). Both analyses of variance are summarised in TABLE 14.

TABLE 14.

One-way analyses of variance between pitch discrimination scores across the four accuracy levels in identification of (1) Piano notes, and (2) Pure tones (PRE-EXP/D).

	Source	DF	S.S.	V.E.	F	P
(1)	Treatments	3	353.00	117.67	2.12	(n.s.)
	Error	41	2271.58	55.40		
	Total	44	2624.58			
(2)	Treatments	3	467.45	155.82	2.96	<0.05
	Error	41	2157.13	52.61		
	Total	44	2624.58			

The judgment immediacy scores (secs.) were analysed similarly, being divided into the four accuracy groups on both tests (1 and 6).

FIG 13a Pitch discrimination ability and identification accuracy

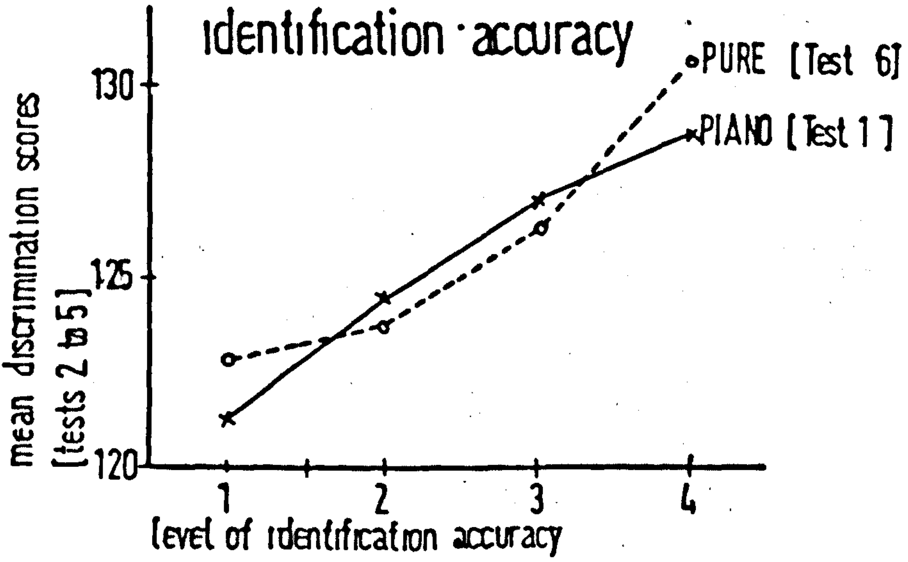
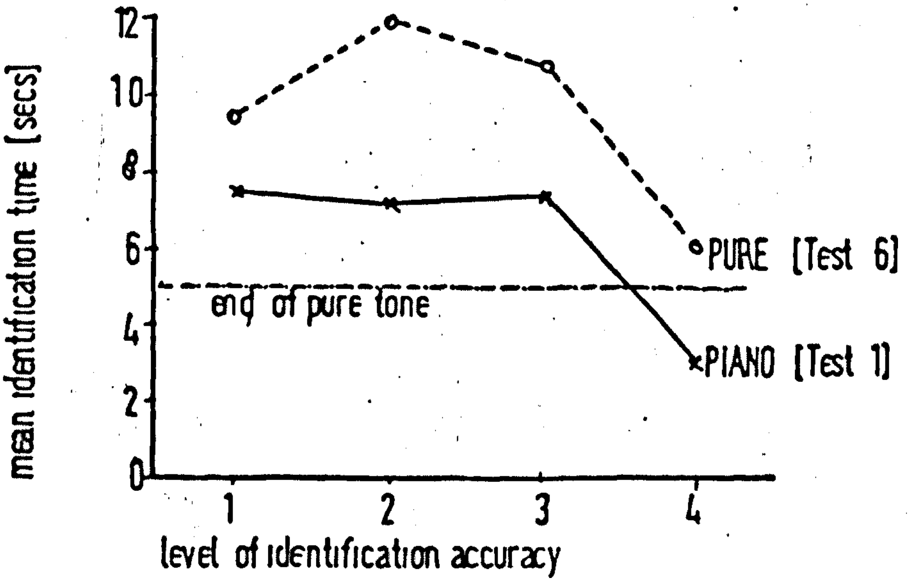


FIG 13b Speed and accuracy of identification



FIGS 13 Relationships between tonal identification accuracy, pitch discrimination and identification speed [PRE-EXP/ D]

A two-way Analysis of Variance design with no repeated measures across the four unequal groups (A) and the twelve notes (B) demonstrated a significant difference between accuracy levels in the speeds of piano-note identification ($F=10.13$; $DF=3,41$; $P<0.01$), and also of pure-tone identification ($F=8.64$; $DF=3,41$; $P<0.01$). These two analyses are summarised in TABLE 15.

TABLE 15.

Two-way analyses of variance between identification speeds (secs.) across (A) the four levels of identification accuracy, and (B) the 12 notes; analyses (1) Piano notes, and (2) Pure tones (PRE-EXP/D).

	Source	DF	S.S.	V.E.	F	P
(1)	Betw subjs	44				
	A	3	1777.58	592.53	10.13	<0.01
	Subj w gps	41	2397.52	58.48		
	Within subj	495				
	B	11	191.80	17.44	1.28	(n.s.)
	AB	33	392.32	11.89	0.87	(n.s.)
	B x Swg	451	6154.20	13.65		
(2)	Betw subjs	44				
	A	3	2255.10	751.70	8.64	<0.01
	Subj w gps	41	3566.29	86.98		
	Withn subj	495				
	B	11	313.95	28.54	1.54	(n.s.)
	AB	33	648.72	19.66	1.06	(n.s.)
	B x Swg	451	8341.81	18.50		

From FIGURE 13b it is evident that the piano-notes were judged quicker than the pure-tones at all accuracy levels - that they should be easier to identify is certainly in agreement with the previous literature, cited in CHAPTER 1. In response to both types of tone, the significant immediacy effects appear due to the unusual speed of the most accurate group; as the 45 subjects had included an unusually high proportion of AP claimants in the first place, this result compliments the observation of previous investigators (CHAP.1) that truly 'absolute' identifications are made with a speed which effectively precludes the likelihood that comparisons with a referent are necessary. Of course we should not conclude that the similar dip in the response speeds to pure-tones of the lowest accuracy group (FIG.14) represents any more than that they were finding the task harder than were the other groups (or trying less at it) and guessing more.

In Bachem's analysis of AP ability (CHAP.1), the definition of genuine AP recognises that certain less familiar timbres may be harder to identify than others; (thus notes on an audio-frequency generator should indeed be harder to identify than those on a piano). If the 'tone-chroma' property arises within the ear, as Korpell (1965) seems to demonstrate, it is to be predicted that its origin is in the information yielded by a tone's harmonics: this notion is supported by the phenomenon of chroma fixation (Bachem, 1948; cited in CHAPTER 1) toward the upper pitch threshold - the harmonics of notes uppermost in the auditory range are beyond threshold and thus afford no information. No subject in the highest pure-tone accuracy group (N=11) failed to score comparably on piano notes, and all were in the corresponding piano-accuracy group (N=13) save one subject (JC) who on his own admission utilises a well-developed memory for relative pitch. Three subjects in the highest (piano) group were less successful with pure-tones, though they were included in the group henceforward to be considered as genuine AP possessors

(N=13) on the grounds of Bachem's criterion. One of the group (AS) reported a perforated ear-drum and anomalous AP ability in certain pitch ranges that closely resembles the case of tonal dip, paracusis and diplacusis reported by Bachem (1948). The omission of AS from the group leaves a compliment of AP possessors totalling 12; four of the twelve subjects who had been studied in the AP group of EXP/C failed to qualify for the present 'high calibre' strain, as did two of the five claimants contacted in the meantime. Other results afforded by the selection procedure prompt the following observations:

- the frequency of note-name usage in identification (FIG.14)is compared with the frequencies observed in chromaesthetic response to each note (FIG.7), and the simple relationship between response frequency and key complexity that provided the explanation of tonal response bias (Main EXP/A) is once again noted;
- an examination of octave errors (as by Bachem,1937 and 1940; described also by Revesz,1953; and in FIGS.2), was not possible in the present analysis as no octave placings were required. However, from the presently emerging notion that tone-chroma qualities may relate to the tonality dimension (FIG.3b) it may be predicted that for AP subjects an atypical proportion of fifth errors may also occur; since the AP pure-tone judgments included 7 errors of a fifth (to either side of target) as opposed to the single fifth-error predicted by linear regression analysis across the error totals of the different intervals (FIG.15), we may tentatively suspect that error analysis may provide the tonality hypothesis with a future source of evidence - for the stimulation of erroneous judgments, tones at threshold may prove useful.

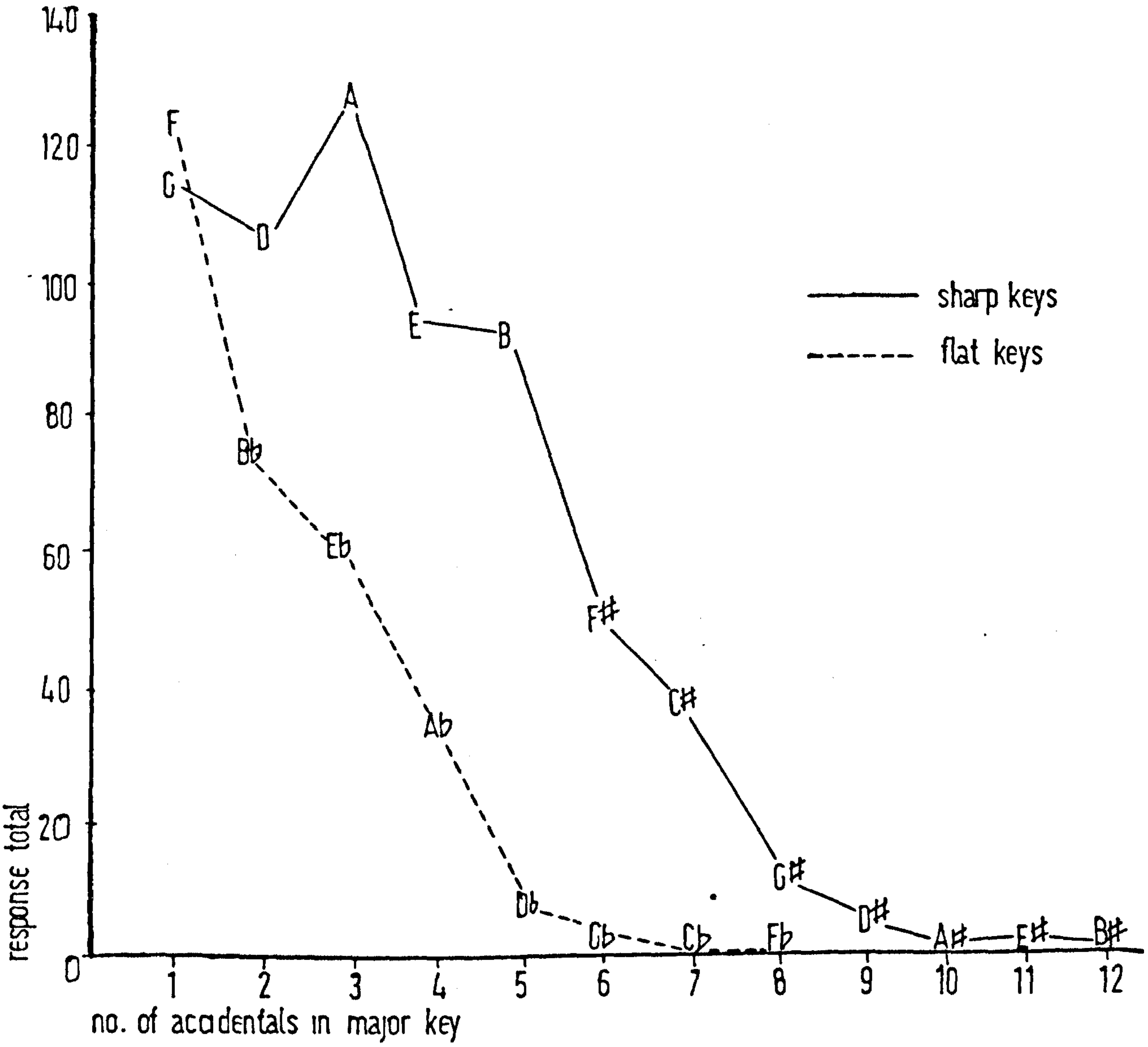
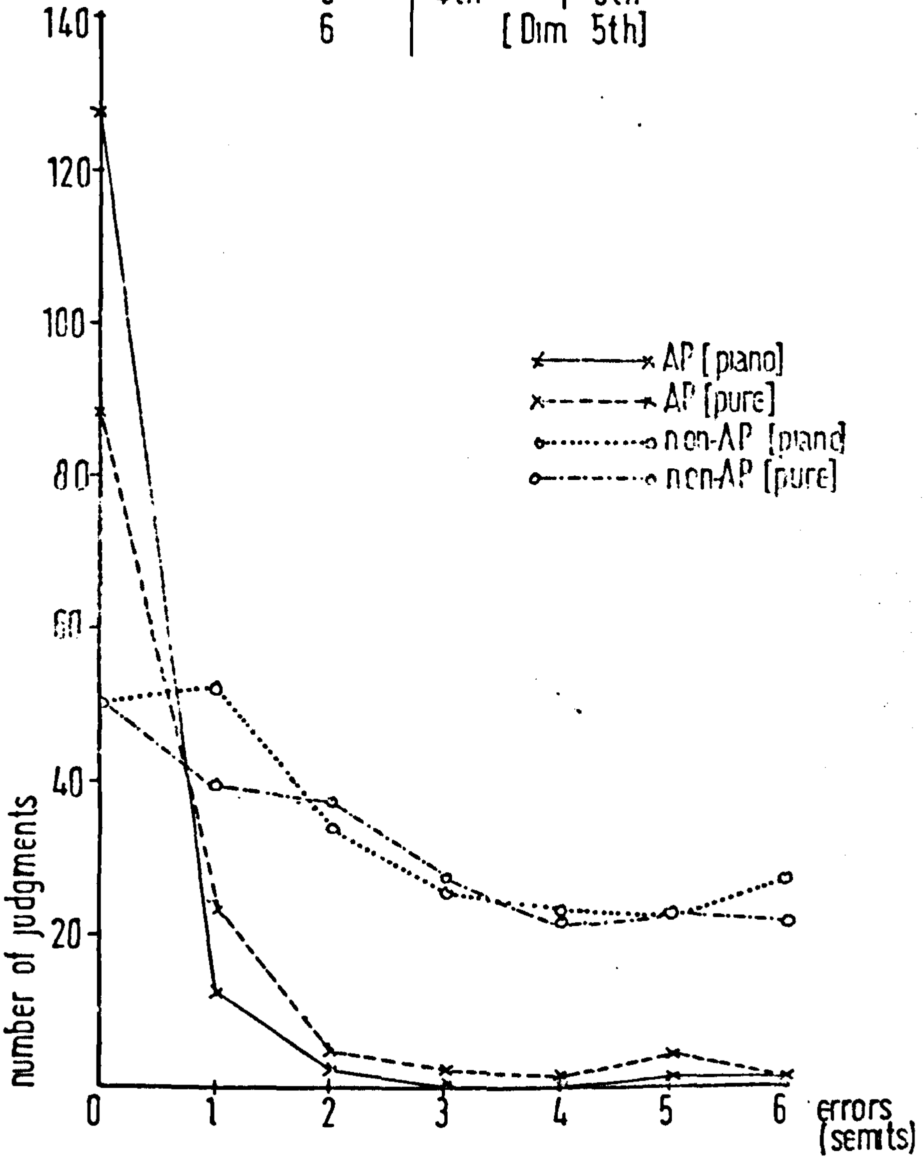


FIG 14 Relationship between response totals [PRE-EXP/D] and major key complexity [cf.FIG. 7]

semit errors between target and response	interval name	interval between target and same note in opposite direction	[=semits]
1	Semitone	Maj 7th	[=11]
2	Tone	Min 7th	[=10]
3	Min 3rd	Maj 6th	[=9]
4	Maj 3rd	Min 6th	[=8]
5	4th	5th	[=7]
6	[Dim 5th]		[=6]



N.B. As octave placings were not required direction of error is not apparent; an error of 11 semitones sharp may thus be mistaken for one of 1 semit flat, 10 semits for 2, and so on. Only the 6 semit interval is the same whether sharp or flat. Therefore, with the exceptions of the latter and correct categories, all totals above are one half of the corresponding totals observed; and an impression of one tail of the error distributions is thereby given [cf. FIGS 2]

FIG. 15 Distributions of accuracy in pitch identification [PRE-EXP/D]

The 12 AP subjects now defined form the experimental group for the main experiment (below); four had taken part in EXP/C, though as before they had no indication of the guiding hypotheses. The control group of musicians not possessing AP numbered 24, twelve of each sex, all naive.

Main Experiment D - PATTERNS OF AUDIO-VISUAL INTEGRATION.

Apparatus, Materials and Method: The experimental situation - once again reflected in FIGURE 10 - required of each subject 16 same-different judgments of 12 different tones (192 in all). Each subject was given prior and simultaneous stimulation by certain colours - subjects were investigated individually by a procedure lasting about an hour. The apparatus, unless specified below, was as in EXP/C. Before the main part of the experiment, each subject was given a sequence of twelve pure-tones for identification at the frequencies used in Selection Test 6 - the sequences were random as in PILOT STUDY A1; each note lasted 0.75 secs. (with rise/decay times as in the Main EXP/C), and pulsed every second; the subject was instructed to respond when ready, guessing if necessary, and to cancel the stimulus as he did so by pressing either of the two Morse keys in front of him. These trials were intended to familiarise the subject with the tones, and to give practice on the response keys. He was then given the following instructions:

> "Please adjust your headphones for comfort and sit in a relaxed position with your arms resting on the table in front of you. From now on you will continue to hear tones that are exactly the same as those you have heard already. The experiment will be divided into 12 sections with 16 trials in each. Each block of trials will be preceded by a tone that is to be known as the Target; you must listen to this until you have fixed it in your mind for comparison with each of the 16 notes to be presented during that block.

These 16 notes are to be known as the Judgment notes; they will be either the same as, or different from the specified Target note. If a Judgment note is the same as the Target, please press the left-hand key on the table; if it is different from the Target (in which case it will be either a semitone above or a semitone below it) please press the right-hand key. Do so as soon as you have made your same/different decision but try to ensure that you do not make a mistake: if you do I shall have means of knowing, but please call out that you realise you have done so.

"Each of the Judgment notes is repeated once a second until you press one of the keys. It will have been preceded for four seconds by a colour, which will be projected onto the screen in front of you: 4 colours are used" (RED, YELLOW, GREEN and BLUE - the subject was now shown the colours in a random order). "At other times the screen will be blank/dark" (THUS) "except when it is flooded with white light prior to and during presentation of the Target note. When the white light is presented you may therefore expect the Target to follow it after 4 secs.; when there is a colour on the screen you will find it a useful cue for the presentation 4 secs. later of a Judgment note. I should like you to look at the colours though to concentrate of course on the tones."

(N.B. At this stage questions from the subject were answered, no practice trials were given, and the first Target note was presented, cancelled in due course by the subject, and immediately followed by the first block of 16 Judgment notes. A rest-pause of about 3 mins. was allowed between each of the 12 blocks, during which E rearranged the colour slides in the magazine of the projector (Plus Ria, Type 2024) for the next block).

The 192 trials featured 4 presentations of each of the 48 permutations of the 4 colours and 12 tones. The colour stimuli were selected from the Cinemoid filter range of Rank Strand Electric Ltd. - they were Primary Red (Code No. 6), Yellow (1), Dark Green (24), and Deep Primary Blue (20); on projection they covered a plain white display area of 75 sq. cm. at 2.4 m. in front of the subject. At each trial the experimenter initiated a sequence thereafter controlled by the clock of the RDP Multi-X: - i.e. automatic operation of the Plus Ria slide-changer to present a visual display of one of the colours, and 4 secs. later, the presentation of a tone at the setting already determined. At the onset of the tone the RDP counter was triggered; it was automatically stopped by the subject's response and the intervening time recorded to the nearest 0.01 secs. With each response the slide-changer moved the magazine onward, interposing a square of card (5 x 5 cm.: the size of each slide) between the light-source and the screen. The recording of errors (wrong key or both at once) was made by noting which of two bulbs on a purpose-built auxiliary relay-block had been illuminated by the response. The next trial was then initiated without delay.

The sequence of Judgment tones in each block was governed by a presentation scheme providing 8 notes the same as the Target and 8 notes different from it - of the eight Differents 4 were a semitone higher than the Target and 4 a semitone lower. The Target notes were presented (in linear semitonal sequence) on the following scale: E=330 cps., F=349, Fsharp=370, G=392, Aflat=415, A=440, Bflat=466, B=494, C=523, Dflat=554, D=587, Eflat=622, E=659; ascending and descending sequences were presented to an equal number of subjects in each group, and for each individual subject the Target notes and Judgment presentation sequences were combined uniquely - thus no two subjects in the same group received a sequence of Judgment tones in conjunction with the same Target note, and each subject accordingly received a unique sequence of the 4 x 48 colour-tone combinations. Since the Target progression was semitonal (ascending or descending) each Target note was the same as one of the Judgment-Different tones in the following block; in an ascending Target progression, the Judgment-Up tone in one block (e.g. Bflat, a semitone higher than the Target A) became the Judgment-Target-Same note of the next, and during the following block it became the Judgment-Down note. Each Judgment note was presented as a Same note 8 times during the whole experiment, and as an Up and a down note (Different) 4 times each: it was paired with each of the 4 colours an equal number of times (and in random order) in each S/D capacity; moreover, the colours were presented an equal number of times (=4) within each block of trials so that the Target-Colour combinations might be analysed as well as the Judgment-Colour pairs. The only anomaly within the scheme was the E stimulus; the Target progressions always began on the E (either Higher or Lower) and ended (if ascending) on the Eflat=622 cps., or (after descending) on the F=349 cps. As a Same-note E thus occurred at 330 cps. or 660 cps. for an equal number of subjects, while as a Different-note it was presented to each subject at the higher and lower frequencies an equal number of times. It was hoped that at least for AP subjects the tone-chroma of E would interact with the colours in a characteristic manner independent of tone-height.

The experiment took place in a room where the only light-sources were the projector and local Anglepoise lighting at E's console; a partition prevented the subject from watching E, his apparatus, or any of his actions. To relieve the hour's monotony a friendly inter-block atmosphere was fostered, though no interruption of the sequence of trials within a block was allowed, and no guidance or feedback was given to the subject at any time. When the main experiment was completed, the manual projector control (by which the automatic control of trials might be over-ridden at any time) was used to show the subject the colours once more as he ranked them in order of brightness (1 as the brightest, to 4 as the darkest). Subjects were then asked to fill in the EPI (Form B), and none refused.

(N.B. A casual observation by several subjects proves useful in the final discussion of results. As may be seen from the photographs in APPENDIX V, the subject's chair backed onto a cabinet on which stood the slide-projector; six of the 36 subjects reported a steady hum emitted by the projector's motor, which the experimenter had not noticed. Two of the subjects (both AP) found the sound quite disturbing, especially when their judgments involved the note A at 440 cps. A comparison by the method of beats between the hum and the variable oscillator tone identified the frequency of the hum as between A and Bflat at app. 224 cps. (i.e. slightly sharper than one octave below the A stimulus). After a close scrutiny of the hum the experimenter could detect various combination tones (octaves, fifths and fourths) vibrating with it in the cabinet; and each of the other four subjects agreed that they had consciously used the main 224 cps. frequency - faint though it was - as a referent in their responses. Clearly the long experimental session had rendered them unusually sensitive. As it was not pointed out to the experimenter until many of the rare AP subjects had completed the experiment, the variable was deliberately left without control during the remaining sessions; and in fact it provides a clue (CHAP.5) to the origin of the effects now to be discussed).

Results: The subjects were in almost complete agreement that Yellow was the brightest colour used, Blue the darkest, with Red and Green sharing an intermediate level (Kendall's $W = 0.86$; $P < 0.01$).

The results of EXP/C have indicated that a connection within a group of subjects between particular tones and colours may not be observed until the wide range of individual differences between the subjects (regarding the direction of their transmodal interaction effects) has been dichotomised. To this end, the measures expressing these interactions (F-scores, and response-time means for each subject) were separately correlated (EXP/C) with the subjects' EPI scores; in consequence, for the AP group, the previously predicted links between Eflat and Red, A and Yellow (EXP/B) were expressed by a significant correlation coefficient between each measure and the Neuroticism scale. In that experiment, Red/Yellow and Eflat/A were the only Colour/Tone factor levels studied, while in the present experiment we have the opportunity to determine whether Eflat will interact to greater effect with Blue, for example; in fact, we may assess the relative strengths of connection between each of the four unique hues and each of the twelve notes in the diatonic scale. In the present analysis, the colour-tone connections are referred to as <u>audio-visual integrations</u>, rather than interactions as previously - for their index is no longer to be an interaction measure following Analysis of Variance. It is hoped that systematic integration patterns may emerge in the fluctuations of audio-visual <u>integration strength</u>, for the two subject groups, with respect to either the semitonal (Linear) or fifths-consonance (Cyclic) tonal sequences.

The measures of integration strength are provided by the correlation coefficients (Pearson's r) between (a) the mean response times of each colour-tone pair, and (b) the Neuroticism and Extraversion scores given by the members of each group (AP vs. Non-AP).

The basic RT's were analysed in two separate ways, covering the possibilities of (a) integration between colours and Target notes, and (b) that which may occur between the colours and each Judgment note. The mean RT's for each note in both analyses (i.e. 48 Target, and 48 Judgment means for each subject) were summed across the four colours, and the proportions (%) of this the total response time for the note were calculated for each colour-tone combination. Each of the 48 colour-tone pairs now has (for each subject) a Target and a Judgment percentage of the tone's RT total for that subject, these percentage scores being correlated with the subjects' N and E scores across the two subject groups. Each group (AP and Non-AP) thus has 192 coefficients of the sort obtained in EXP/C: on that occasion, as stated, correlations between Eflat and Red, Eflat-Yellow, F-Red, and F-Yellow alone were possible, while the present set of coefficients represents the 48 pairings for both Target and Judgment, and in correlation with both N and E.

Suitably high coefficients have the following meanings:-

(N+) positive relationship between integration strength and Neuroticism indicating that the more neurotic a subject the higher (=slower) his response time, given the particular colour-tone combination in question; and the less neurotic, the faster;

(N-) higher levels of neuroticism are related to the faster speeds in this colour-tone situation, and lower levels to the slower speeds;

(E+) more extravert subjects give the slower responses, while introverts give the faster ones;

(E-) introverts are slower than the extraverts; As presented in TABLE 16, the coefficients of each subject group were analysed for variance on the four factors of (A) Tonal analysis type, Target vs. Judgment; (B) Integration Correlate, Neuroticism vs. Extraversion; (C) Colours; and (D, the observations within each cell) Tones. Repeated measures were specified on (A),(B), and (C); the results are summarised in TABLE 17. (N.B. A re-analysis of these data, in which the raw scores were corrected for possible response bias in the tonal and colour factors as in EXP/B, gave the same results as are reported next; the tonal bias was not significant, and no group tendency to a colour bias was observed; it thus appears that in the group analysis the significant biases of individual subjects cancel each other out).

The main effect of interest in the four-way variance analysis is CD, the overall two-way interaction between the factors of Colour and Tone; in both subject groups CD is significant, the AP effect at $P < 0.001$, and the Non-AP effect at $P < 0.01$. No one-way effect is significant in either group, and the only other significant two-way interaction occurs after pooling of non-significant error terms in the Non-AP group - between Colours (C) and the Neuroticism-Extraversion factor (B): whereas the raw response proportions yielded no group colour bias, their differentiation by the EPI scales in this manner yields an effect significant at $P < 0.05$. Of the 384 coefficients in TABLE 16, 28 are significant at P = at least 0.05 (i.e. 1 in 14, a greater proportion than by chance). The one-way factors (A), (B), and the two subject groups have 14 significant scores each. However, these sets of 14 are subdivided less evenly (9:5 in each case), with more AP significances among the Neuroticism

TABLE 16 Correlation coefficients (group response times with N and E) for each colour, tone, tonal analysis type, and subject group (EXP/D).

AP Subjects R(0.05)=0.576, R(0.01)=0.708

		N				E			
		R	Y	G	B	R	Y	G	B
TARGET	E	0.217	0.085	0.418	-0.516	0.366	0.141	0.276	-0.552
	F	0.019	0.144	-0.168	0.218	0.192	0.117	-0.429	0.672*
	Fsharp	0.310	0.009	-0.594*	0.188	0.088	0.509	-0.551	-0.146
	G	0.595*	-0.243	0.046	-0.389	-0.075	-0.312	0.165	0.145
	Aflat	0.352	-0.570*	-0.098	0.318	0.195	-0.229	0.100	-0.101
	A	0.298	-0.530	0.538	-0.161	0.582*	-0.396	0.375	-0.713**
	Bflat	0.366	0.510	-0.288	-0.427	-0.066	0.288	0.228	-0.415
	B	-0.350	-0.087	-0.124	0.648*	-0.064	-0.200	0.532	-0.360
	C	0.048	0.321	-0.331	0.203	-0.133	-0.237	0.320	-0.155
	Dflat	0.041	0.289	0.025	-0.261	0.234	0.465	-0.668*	-0.081
	D	0.024	0.093	-0.134	0.012	0.167	-0.434	0.141	0.054
	Eflat	-0.149	0.609*	-0.141	-0.144	-0.386	0.412	0.267	-0.237
JUDGMENT	E	0.055	0.016	0.155	-0.258	0.325	0.223	-0.140	-0.217
	F	-0.154	0.354	-0.451	0.250	-0.298	0.265	-0.200	0.043
	Fsharp	0.221	-0.429	-0.027	-0.171	0.027	0.203	0.005	-0.301
	G	0.574*	-0.145	-0.356	0.106	0.166	-0.352	0.039	0.215
	Aflat	0.615*	-0.587*	-0.117	-0.150	0.334	-0.209	-0.377	0.113
	A	0.239	-0.332	0.440	-0.218	0.559	-0.191	0.381	-0.672*
	Bflat	0.004	0.019	0.037	-0.074	-0.035	-0.159	0.325	-0.249
	B	-0.318	-0.098	0.029	0.359	0.315	-0.157	0.422	-0.328
	C	0.198	0.800**	-0.441	-0.024	-0.447	-0.059	0.433	-0.199
	Dflat	0.456	0.146	-0.063	-0.286	0.429	0.053	-0.208	-0.151
	D	-0.029	0.424	-0.311	0.149	-0.177	-0.122	0.144	0.276
	Eflat	-0.268	0.144	0.086	-0.044	-0.145	0.084	0.162	-0.306

Non-AP Subjects R(0.05)=0.404, R(0.01)=0.515

		N				E			
		R	Y	G	B	R	Y	G	B
TARGET	E	0.220	-0.078	0.107	-0.250	-0.263	-0.114	0.062	0.239
	F	-0.234	0.257	-0.123	-0.059	-0.246	0.094	-0.227	0.325
	Fsharp	0.029	-0.324	0.106	0.164	-0.046	0.085	0.157	-0.119
	G	-0.253	0.272	0.037	-0.115	-0.299	0.200	0.039	0.061
	Aflat	-0.095	-0.217	0.287	0.085	-0.381	0.191	0.046	0.198
	A	-0.149	0.089	0.058	-0.026	0.153	0.120	0.044	-0.275
	Bflat	-0.190	-0.040	0.252	0.043	-0.101	-0.183	-0.071	0.263
	B	0.331	-0.046	-0.430*	0.437*	0.009	0.384	-0.479*	0.181
	C	-0.016	0.147	-0.115	0.000	0.049	-0.134	-0.002	0.085
	Dflat	-0.237	-0.234	0.380	0.102	0.265	0.242	0.222	-0.592**
	D	-0.101	-0.072	-0.017	0.230	0.002	0.066	-0.147	0.125
	Eflat	0.151	-0.140	-0.057	0.040	-0.287	0.503*	-0.011	-0.236
JUDGMENT	E	0.235	-0.031	-0.088	-0.037	-0.486*	0.415*	-0.249	0.266
	F	0.336	0.307	-0.534**	-0.079	-0.232	-0.184	0.009	0.383
	Fsharp	-0.014	-0.310	0.080	0.203	0.000	0.139	0.271	-0.284
	G	-0.049	-0.044	0.255	-0.079	-0.362	0.398	-0.229	0.293
	Aflat	-0.377	0.076	0.324	-0.014	0.085	-0.176	0.003	0.103
	A	-0.114	0.040	0.098	-0.018	0.115	0.412*	0.026	-0.398
	Bflat	-0.081	-0.065	0.001	0.129	-0.233	0.215	-0.387	0.406*
	B	0.146	0.030	-0.334	0.222	-0.158	0.053	-0.084	0.160
	C	0.157	-0.087	0.048	-0.202	0.241	0.083	-0.413*	-0.078
	Dflat	-0.284	-0.003	0.171	0.113	-0.175	0.234	0.317	-0.507*
	D	0.378	-0.135	-0.351	0.086	0.028	-0.039	-0.219	0.208
	Eflat	-0.480*	0.083	0.462*	-0.097	0.011	0.289	0.154	-0.355

(* P < 0.05 ** P < 0.01)

TABLE 17.

Significant effects yielded by the four-way analyses of variance on the coefficients of TABLE 16 (EXP/D); factors (A) Tonal analysis type, Target vs. Judgment, (B) Integration Correlate, Neuroticism vs. Extraversion, (C) Colours, and (D) Tones; analyses (1) AP subjects, and (2) Non-AP subjects.

	Source	DF	S.S.	V.E.	F	P
(1)	CD	33	8.83	0.27	10.04	0.000
	ACD	33	2.26	0.07	2.57	0.004
	BCD	33	4.50	0.14	5.11	0.000
	ABCD	33	0.88	0.03		
(2)	CD	33	3.48	0.11	2.39	0.007
	BCD	33	2.79	0.08	1.92	0.033
	ABCD	33	1.45	0.04		
	BC	3	0.43	0.14	3.00	0.034
	Pooled error	110	5.23	0.05		

and Target correlates than among those of Extraversion and Judgment; and in the Non-AP group vice versa. The differential influence of Colour on the response times to individual tones may readily be appreciated by a glance, along each row of TABLE 16, at the wide-ranging contrasts between positive and negative coefficients for the same tone within each group of four hues. In the following analysis, however, we wish to determine whether the coefficients for each hue vary systematically between the tones - and thus we concentrate on the column effects.

The earlier prediction that the members of certain colour-tone pairs may integrate to a greater or lesser extent than those of other pairs (whether by facilitation or inhibition) indicates that in a systematic integration pattern a coefficient of zero may be as meaningful as that which is significantly positive or negative. In a valid scheme one would expect of course that each note should have a significant individual integration with at least one colour, but first we should establish whether the coefficients (loadings, as it were, on each colour factor) relate within a structural scheme at all, and to this end each of the possible rationales on which such system may be based (Target and Judgment, Neuroticism and Extraversion, Linear basis and Cyclic) must be probed. In the search for a rationale underlying the colour-tone effects in both subject groups, each of the 16 dimensions (12 notes in each) given in TABLE 16 was examined for trend: as in EXPS/A and B, colour scores across the semitonal sequence were subjected to linear regression analysis, and those around the circle of fifths to harmonic analysis.

No significant linear trend was found in either group; however, significant cyclic trends occur on several dimensions, involving each colour but Blue. In the Non-AP group the coefficients denoting differentiation of Yellow-Target scores by Neuroticism, and Green-Judgment scores by Extraversion each fit a sinusoidal curve fluctuating across the sequence of fifths at $P=0.002$ and $P<0.05$ respectively (the Red-Judgment/Neuroticism coefficients do likewise at $P=0.06$). In the AP group the coefficients linking Red-Judgment and Extraversion correspond to their sinusoidal first harmonic at $P=0.04$, as do those of Yellow-Target and Extraversion. A Yellow-Target effect is thus noted in both groups, though they vary with respect to the personality correlate to which they refer. The significant effects are represented schematically in FIGURES 16, and the details of their 1st harmonics are given in TABLE 18. It is surprising - but not yet crucial - that in these four significant sinusoidal effects only one score out of the total 48 is individually significant. Of course, there is as yet no actual reason to suppose that a perfect sinusoid is the best representation of the rationale at all; certain of the values in this and previous experiments have approximated to it, though may fit different structures even better. The irregular sub-peak at F, for instance, in the EXP/B brightness curve (FIG.9c), may represent a meaningful tendency for rationalisation on a basis resembling a sinusoid, but which the perfect sinusoid represents with less than total accuracy. We should look for the replication of such irregularities as the F tendency in seeking the true rationale for these phenomena.

Also unpredicted was the emergence of Extraversion as a scale differentiating the colour-tone integration effects involving Yellow - only the Neuroticism index has acted as a significant directional correlate previously (EXP/C). Furthermore, the Yellow-Target/E effect shown in FIGURE 16a is correlated with the Neuroticism effect of FIGURE 16b at $r = -0.489$; thus, as previous work (cited above) has suggested, the two indices N and E may not always be as independent as Eysenck's theory maintains. Eysenck himself (1964) acknowledges the customary slight (negative) relationship between them, but none as high as -0.489. In isolation this coefficient demonstrates no more than a tentative relationship between the effects. However, that the effects have an apparent structure in common suggests the agency of a factor more basic to the rationale of the present situation than either index: it indicates the possibility that, by rotation of the axes N and E, a main effect of the present task may be isolated, cutting obliquely through both axes.

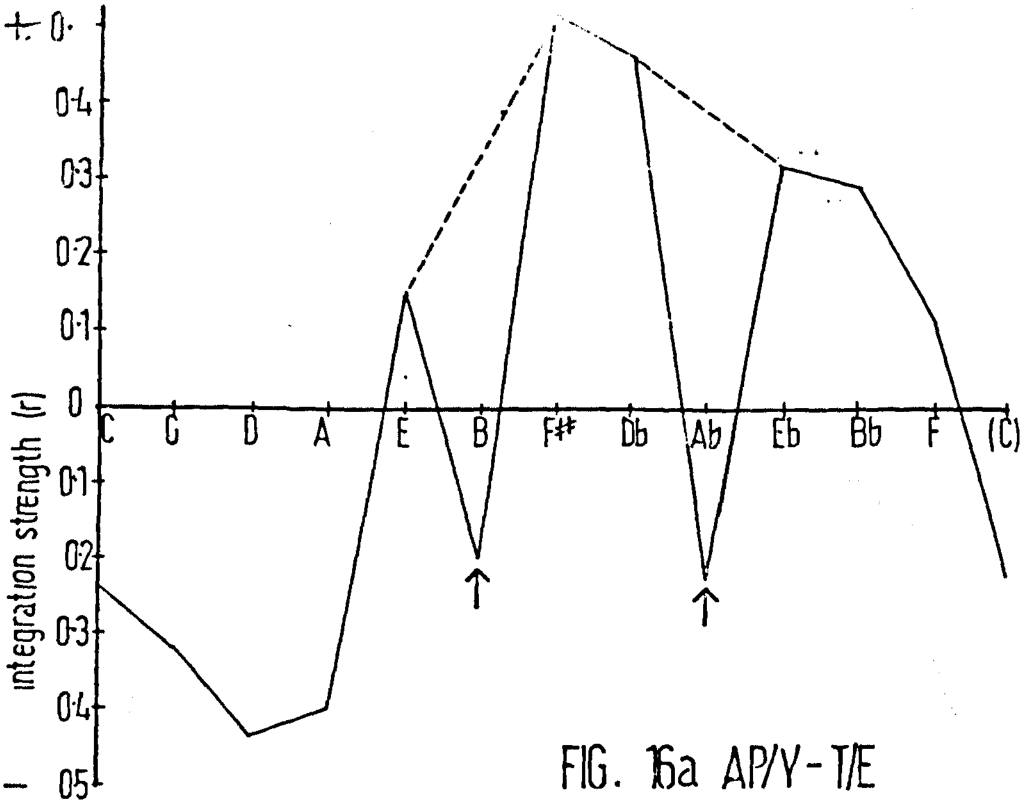


FIG. 16a AP/Y-T/E

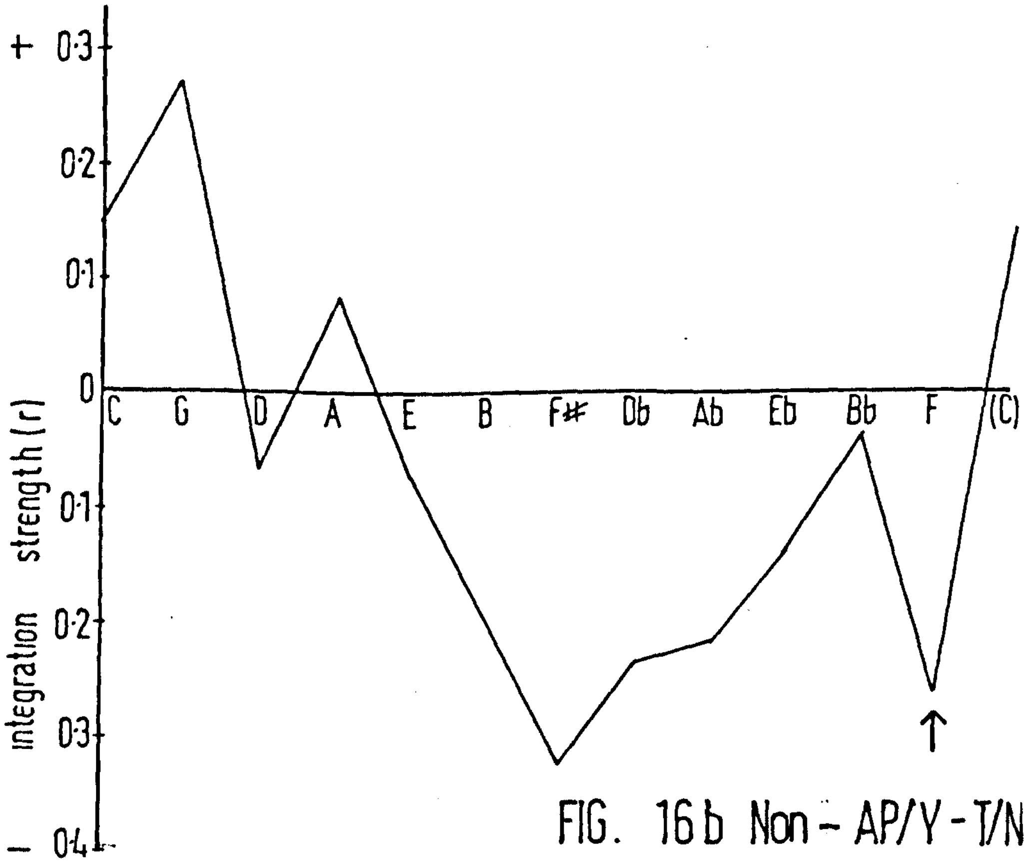


FIG. 16b Non-AP/Y-T/N

FIGS. 16 a, b Significant sinusoidal integration structures [Y] [EXP/D] [*n.b.* anomalous scores ↑]

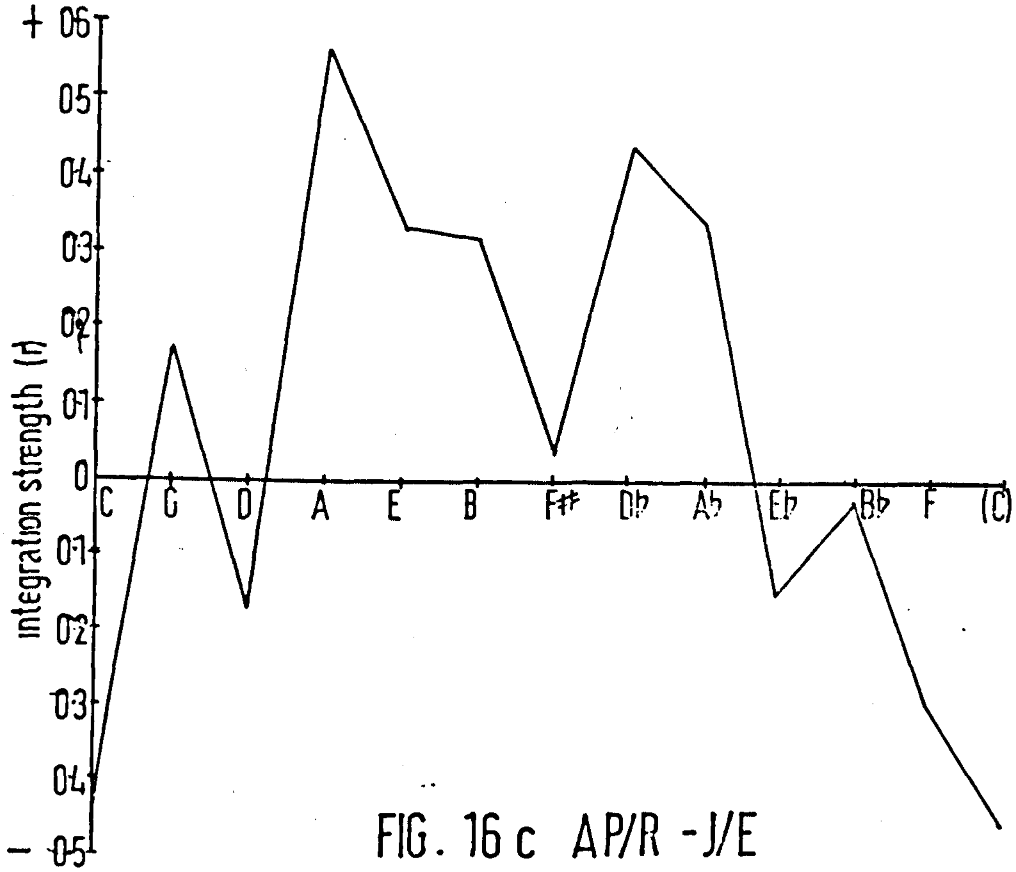


FIG. 16 c AP/R -J/E

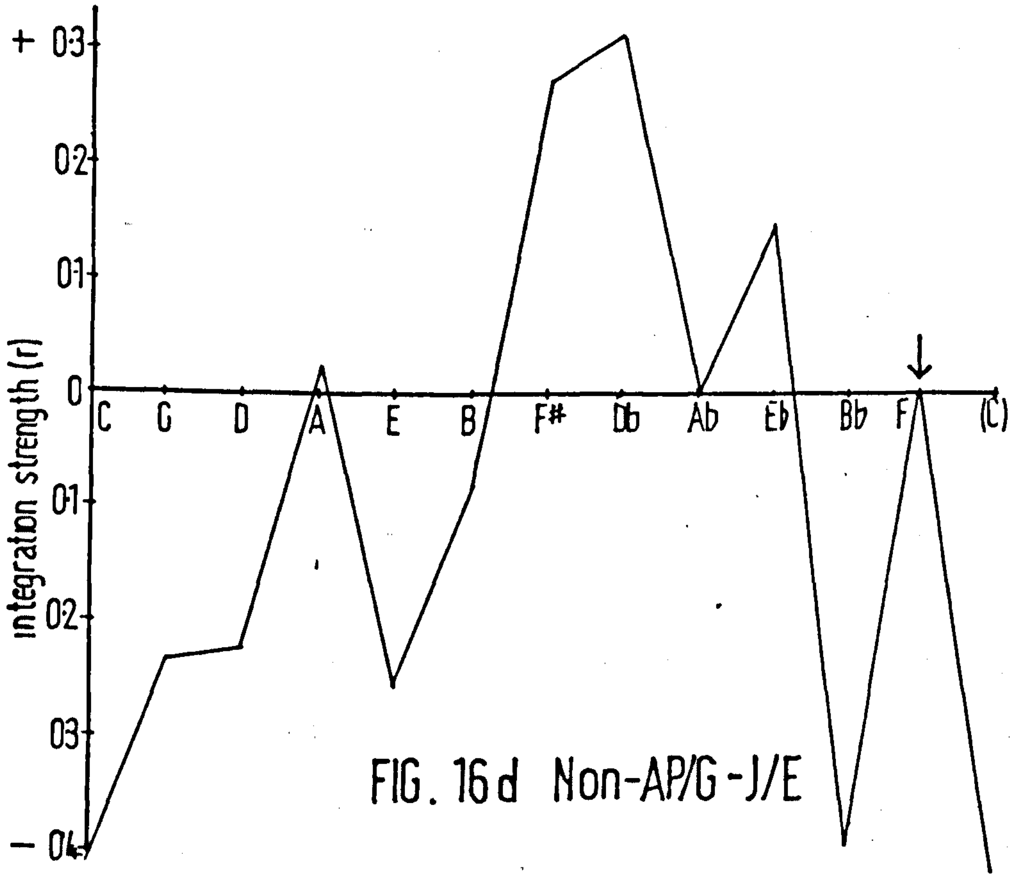


FIG. 16 d Non-AP/G -J/E

FIGS. 16 c,d Significant sinusoidal integration structures [R,G] [EXP/D] [n.b. anomalous score: ↓]

TABLE 18.

The four 1st-harmonics found significant after harmonic analyses of the sixteen 12-note dimensions in TABLE 16.

	AP/R-J/E	AP/Y-T/E	Non-AP /Y-T/N	Non-AP /G-J/E
C	-0.19	-0.19	0.18	-0.28
G	-0.09	-0.30	0.19	-0.29
D	0.06	-0.33	0.13	-0.25
A	0.21	-0.27	0.04	-0.15
E	0.33	-0.13	-0.08	-0.04
B	0.39	0.04	-0.18	0.07
Fsharp	0.37	0.21	-0.24	0.14
Dflat	0.27	0.32	-0.25	0.16
Aflat	0.12	0.35	-0.20	0.11
Eflat	-0.04	0.29	-0.10	0.02
Bflat	-0.16	0.15	0.01	-0.10
F	-0.22	-0.02	0.11	-0.20
Amplitude	0.30	0.34	0.22	0.23
Phase	3.24	4.62	0.85	4.06
(F)	4.70	4.68	12.95	4.25
P	0.04	0.04	0.002	0.05

The question of rotation is in itself a controversial one. On the one hand it is true that blind statistical manipulation of one's data may lead to levels of the most intricate fancy, and that rotation is a more ingenious method for disguising realities than are many statistical techniques. Yet if one has anticipated at each stage of the analysis the changes of meaning that the data will undergo, then not only may the manoeuvre's validity be checked, but subsequent, more meaningful patterns in the data be rationally interpreted.

> "Many workers have used correlated factors" (cf. Colour and Tone) "but have not gone on to extract second order factors, thus leaving their analysis incomplete and difficult to interpret ... (I)t has always appeared one of the great weaknesses of British writers that they have accepted without question centroid factors as they emerge from the analysis, in spite of the obvious fact that these factors are not invariant but depend entirely on the sample of tests included in the battery" (cf. 12 notes of the scale). "It might be possible to ... rotate centroid factors into a more meaningful pattern, but none of the writers who have used this technique has made any attempt to get away from the factor patterns as originally obtained. Indeed the very existence of this problem has not, to the writer's knowledge, been discussed before." (EYSENCK,1970).

It would certainly appear from Eysenck's advice that rotation of axes may be an appropriate method by which higher levels of meaning may be wrung from the present data; and the fact that our first-order factors (N and E) were extracted on a previous occasion (Eysenck,1964) need not deter us from following his advice in performing certain tentative rotations on the present data. Prior to selecting a rotational method for use on these data, a number of rotated factor solutions in Harman (1967) were compared by means of the Tucker Coefficient of Congruence (Harman,p.269); they were further compared with solutions obtained by a combination of Kaiser's Varimax method, and the Gram-Schmidt Orthogonalisation Process (Harman,p.239). The Varimax method (APPENDIX IV), in proving more reliable than either of the others, was selected accordingly. While assuming that the axes are orthogonal, it allows a margin for tolerance in this respect. In an extensive series of Varimax manipulations of the TABLE 16 scores, a number of 'more meaningful' effects became apparent:-

(1) the accumulation of significant scores in both subject groups on the axes previously representing Extraversion;

(2) the accumulation of significant AP scores on the Target axes, and Non-AP scores on the Judgment axes;

(3) the accentuation of near-sinusoidal integration structures on certain of the colour axes, in manners suggesting, for the Non-AP groups in particular, that the integrations vary on a brightness dimension which the individual hues variously represent.

(N.B. The previous suggestion (CHAP.3) that such relationships may be due to Yellow's quality as the brightest colour - rather than to the actual hue - is now objectively supported by the significant concordance between subjects' brightness ratings of the four hues).

Yet even the suitability of the Varimax method in the present context is debatable. If we regard the inter-relationships between N and E as causal - querying indeed the validity of the Eysenck dimensions themselves - the method is applicable, for the main effects cutting across these axes are seen as independent of the oblique relationship between them. But the degrees of obliquity differ from one dimension of the data to another; and if we recognise that the axis inter-relationships may indeed be dependent on the various effects that the situation elicits - each dimension (N and E) relating separately to different aspects of the task - then we must acknowledge that the orthogonalisation of scores by a method such as the Gram-Schmidt Process will only serve to conceal these effects. Eysenck's advice (above) on the value of such manoeuvres should thus be followed with caution. The levels of axis inter-relationship in these data may not be rigorously identified until the relationships between each factor (suggested by the three interpretations above) have been investigated individually. And we cannot even be sure that a method of oblique rotation is appropriate. Meanwhile, we offer the interpretations of these rotated effects with due reserve, as possibly relevant to the various points to be made in the following chapter, and to the future examination of the phenomena we have reported.

In the existing data, differences in the number of significant N and E scores, also of Target and Judgment scores between the two subject groups, have already been mentioned. In terms of either the total number of significant scores or of their correspondence to the sinusoidal curve, no difference between the groups is apparent. Once again the cyclic scale proves particularly susceptible to a sinusoidal relationship with Yellow. With the exception of the anolmalous scores at B and Aflat (FIG.16a), the two peaks of the AP curve for Yellow (in which differences between subjects are related to Extraversion) bear a striking resemblance to those of the EXP/B brightness curve in FIGURE 9c. FIGURE 16b demonstrates a similar sinusoidal fluctuation across Yellow by the Non-AP Neuroticism coefficients, also a repetition of FIGURE 9c's irregularity at around the F/C area, which supports the earlier argument that a perfect sinusoid may not in fact be the final representation of the rationale underlying these phenomena.

When the present data are considered in isolation, any systematic integration pattern is open to two interpretations: the positive and negative peaks of a curve may each represent facilitation or inhibition of the colour to which the curve relates. However, on considering the EXP/D integration patterns in parallel with the association curves of EXP/B, we may make the following inferences:-

(1) that the reversal of Yellow effects between FIGURES 16a and b is consistent with the customary negative relationship between the two EPI dimensions; accordingly,

(2) that the G-D-A peaks represent Yellow (=Brightness) facilitation by extraverts and non-neurotics (inhibition by introverts and neurotics), while

(3) the Fsharp-Dflat-Aflat peak represents Yellow (=Brightness) inhibition (=Darkness facilitation) by extraverts and non-neurotics (Darkness inhibition by introverts and neurotics); and

(4) that the Red and Green curves (FIGS.16c and d), though less regular than those for Yellow, follow a pattern easily identified with the brightness rationale thought to underly FIGURES 16a and b (i.e. Mid-brightness facilitation at the F-C-G peaks by extraverts, inhibition by introverts).

Explanations for these effects, and for the anomalous scores, are offered in CHAPTER 5, and the results of the four main experiments drawn together; implications for the theories of perceptual capacity, imagery, and musical cognition are suggested, and relationships between Absolute Pitch, synaesthesia, and aspects of musical ability discussed.

Chapter Five

THE VISUAL EAR

5.1 KEY CHARACTERISTICS: A RATIONALE.

The four main experiments indicate that the pitch quality of a sound may interact with visual stimuli in two ways: (1) relating to its position in the Tone-Height continuum, a linear scale divided musically into semitones, and (2) with respect to a quality dubbed Chroma, which evidently relates to the sequence of fifths, a cyclic scale expressing the relationships between musical tonalities. Pursuing the hypothesis of a two-component tonal helix, it has been suggested that these two types of interaction may together underly the phenomena of Absolute Pitch and Tonal Chromaesthesia. The studies of audio-visual integration pattern suggest that the visual variable equated with both of these dimensions is 'brightness' rather than hue per se; and in this final chapter the following questions must be tackled:-

(1) How does a tonal 'brightness' characteristic come to be equated with these two musical dimensions (Height and Chroma)?

(2) Why do auditory and visual stimuli interact differentially in decision time?

(3) Why does a visual stimulus interact with a tone on its linear scale in one situation and with its cyclic scale in another?

(4) How, and to what extent, do personality characteristics determine the facilitation or inhibition of an intersensory interaction?

(5) Do these interactions indeed relate to the AP and chromaesthetic capacities?

(6) Why do the visual stimuli interact with Target notes in the AP group, and with Judgment notes in the Non-AP group?

(7) What is the explanation for the repeated failure of certain ('anomalous') scores to fit into the general interaction patterns of both groups in EXP/D?

In the discussion in CHAPTER 2 of the types of colour-tone synaesthesia, we concluded that the high degrees of concordance between reported imagery may relate to a more basic mechanism than simple chance association. While various artefactual reasons deeply rooted in the culture may be responsible for associations of low notes and dark colours, high notes and bright colours, the basis for a cyclic relationship between colour-tone associations is rather more subtle. Since apparently only one composer (Scriabin) and two little-known psychological articles (Sabaneev, 1929; Carroll & Greenberg, 1961) have ever suspected that the rationale in question is provided by the circle of fifths, it is hardly likely that the system demonstrated is due to common musical folklore. In our examination of these phenomena a most beguiling course at this stage would be to develop the earlier intimation (CHAP.2) that normal hearing is equivalent to the state of total colour blindness wherein only the qualities dark (= low), bright (= high), and the intermediate shades are recognised: and that Absolute Pitch is the counterpart of full colour vision. Such an avenue offers several attractive opportunities: to categorise the types of chromaesthesia in terms analogous to the known levels of partial colour blindness, to seek evidence for trichromatic and opponent-process models of hearing, and to speculate on the neural coding by which (fancifully) qualities of all the senses may be conveyed! As yet, of course, we would have empirical support for none of these notions. The main outcome of the present experimentation has been evidence indicating the validity of tone-chroma as an objectively measurable phenomenon, and demonstrating the systematic fashion in which it fluctuates (FIGS.8,9 and 16); no causal explanation is apparent in this evidence for the process whereby tone-chroma is perceived, though in our further investigations we shall now have reason to search for a mechanism which recognises qualities varying sinusoidally on the tonality dimension.

The following proposal for a mechanism of this sort may thus serve two purposes: to dispel the air of mystery that has surrounded the concept of a second pitch quality since its initial advancements by Bachem and Revesz (CHAP.1), and to suggest an immediate channel for further research. For we shall attempt to relate the phenomena to known perceptual abilities. Let us first examine the <u>structural nature of a key</u>. In previous theory the different keys are (structurally) equivalent, having been so since the adoption of the Equal Temperament tuning system (CHAP.2). But despite the various protestations to this effect already quoted, one author (Harker, 1937) has seriously considered whether in practice there may not be a definite limitation to the equivalence that a human tuner can achieve. From CHAPTER 2 it will be recalled that in Equal Temperament no interval is as perfect as the mathematical ideal: each interval is tuned fractionally sharp or flat. The method traditionally described - we refer solely to the <u>tuning of keyboard instruments</u> for the moment - relies on the discrimination of beats that arise from imperfect unison combinations of tones and from mistuned consonances (Harker,1937; Corso,1954; Wood,1962). Of course, an ideal method would be to adjust the tones to perfect unison with ready-specified standard frequencies, as emitted by electronic devices or a set of tuning forks: however, for all practical purposes the method of beats is considered quite accurate enough. By counting the number of beats between intervals the tuner adjusts each frequency until he has obtained the right degree of imperfection for each interval. The interval emitting the clearest beats is the imperfect unison, and the area of the keyboard at which beats are most easily counted is around A=440 cps. The procedure (discussed in length by Harker, 1937; and by Wood, 1962) is laid down as follows:-

(1) The central A-string is tuned to perfect unison (no beats) with the standard fork; the frequency of the standard (it has varied considerably over the centuries) was fixed at A=435 by the Paris Academy of 1858 (Apel, 1944) and at 440 cps. by the British Standards Institution in 1939.

(2) Next in order of clarity are the beats issuing from the mistuned consonances of the octave, fifth and fourth; thus, working from the A=440, either an octave A, or the D or E strings above or below it, are tuned to perfect consonance with the A, then deliberately mistuned until the correct number of beats is produced. The correct tempered frequency of D below the standard A is 293.6648 cps., and its third harmonic is 880.9944; the latter frequency beats against the 2nd harmonic (=880.00) of the A, and the number of beats is thus 0.9944 per second, or 10 beats in 10.1 seconds.

This - if he is to do his job with total accuracy - is what the tuner must count. Bearing in mind that he must keep to this level under the worst possible conditions, we may conclude with Harker (1937) that

> " ... even a first-class tuner is unlikely to realise an equitonic interval on a keyboard instrument with exactitude. As by no means all tuners merit inclusion in this category it is permissible to doubt whether such ... methods can result in anything better than a 'shady' substitute for the alleged equal temperament."

Indeed Harker (echoed by Wood, 1962) doubts whether many tuners count the beats at all: certainly, even an approximation to equal temperament by this method must involve - at over 10.1 secs. per interval - many hours of work per keyboard. Harker thinks it more probable that tuners typically adjust the fifth or fourth to perfect consonance and then give a quick twist to their spanner rendering the note either sharp or flat by 'a very small amount'.

(3) The mistuning of octaves, fifths and fourths continues within the central region of A=440 until eventually one of the octave A-strings is reached (220 or 880 cps.); the particular sequence to this point may differ according to individual tuning habits. If the A-string was followed by the E-string a fifth above it, the next note (other than one of the octave E's) would necessarily be a B; but if the D-string (a fifth below A) had been the next, the following fifth would have been at G. Either way the 'mistuning' proceeds by ascending or descending fifths until the return, full circle, to A. If the consonance of a fourth had been employed, the sequence would have been the same, since an ascending sequence of fifths is the same as a descending sequence of fourths. The tuner may combine judgments of fifths, fourths, and octaves at will without ever disrupting the sequence that (clockwise or anti-clockwise) the circle of fifths describes.

Let us suppose that a tuner's accuracy is indeed a fraction less than perfect; that each of his initial fifth or fourth adjustments involves <u>one unit of error</u>, either sharp or flat. Working from the A by octaves, fifths and fourths, his first step is to the D or E in either direction; his next, to a G or B, may well involve a unit of error in the opposite direction to that of his first, thereby cancelling it out. But it is equally likely to err in the same direction as did the first, so that the error total, in relation to the zero error at standard A, now stands at two. There is no way of checking the accumulation of error until the sequence has arrived eventually at the octave A; for no interval less consonant than the octave, fifth or fourth provides beats clear enough for this purpose. By the time there is a second A for octave comparison with the initial standard, the accumulated error should be large enough for detection. However, any adjustment of the octave A at this point impairs the accuracy of its relationship with the fourth or fifth that preceded it in the tuning sequence so far - so this note (E or D) must be adjusted also. By the testing of intervals in this way, and by playing long, smooth and sustained harmonies, the tuner may remedy a certain amount of his error, returning (and re-tuning) in the cyclic direction he has come until he arrives back at the sequence's mid-point. Beyond this point no further eradication of error is possible.

> "To avoid accumulation of errors, which, though individually imperceptible, may, at the conclusion of such a series of operations, have attained unacceptable proportions, a more prudent procedure would be to start from (A) and tune in descending fifths and ascending octaves as far as the half-way point (Eflat), and then to work backwards from the other end, tuning from (A) by descending octaves and ascending fifths until a half-way point is again reached, which must be the same note (Eflat)." (HARKER, 1937).

While Harker's suggested procedure may certainly save time, the error that will have accumulated by the end of it is still greatest at Eflat.

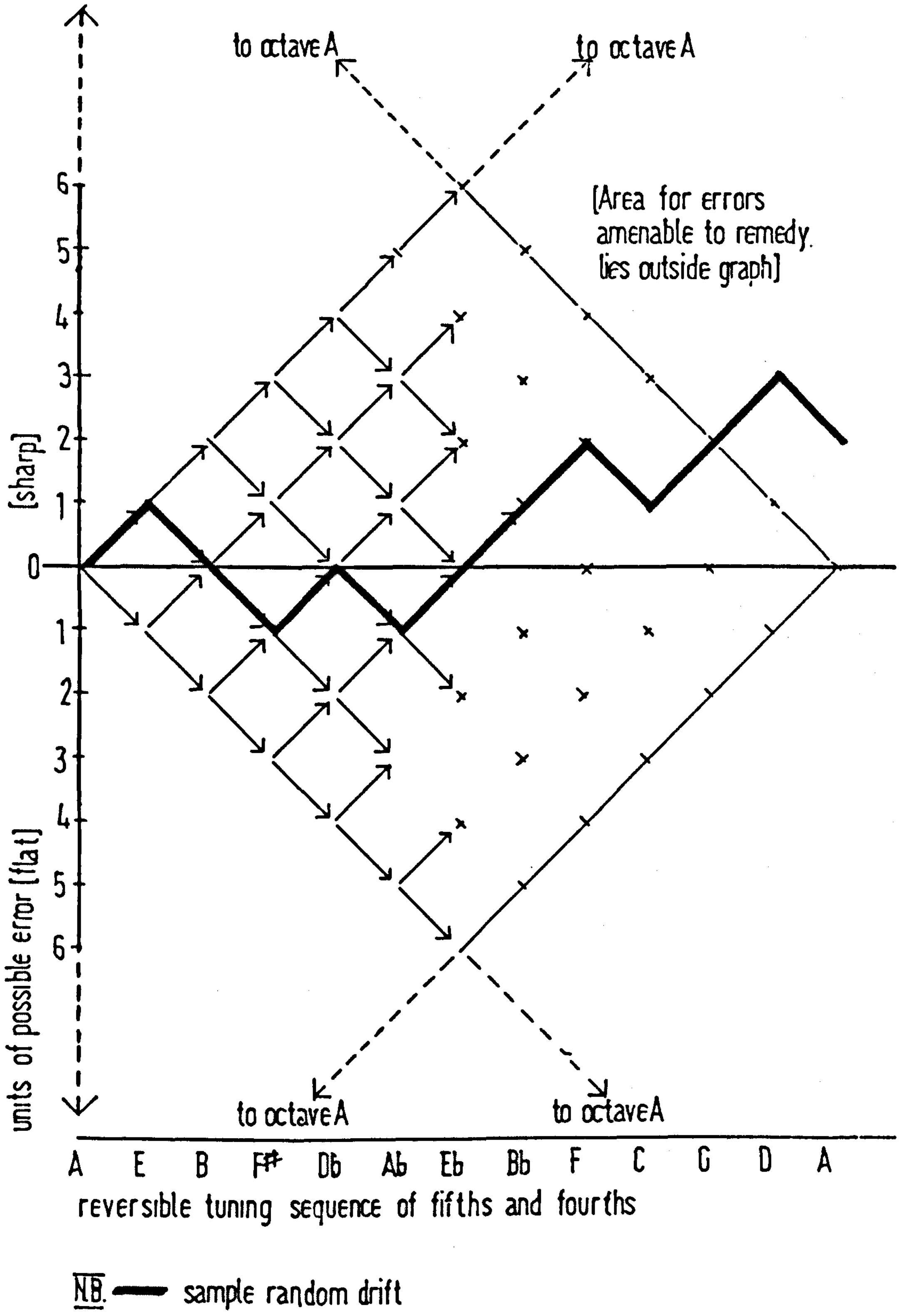


FIG.17a Theoretical possibilities for error in equitonic tuning drift [clockwise sequence]

The process that has been described is represented in <u>FIGURE 17a</u> in which each of the possibilities for a sharp or flat tuning error on each note is given. The FIGURE illustrates the initial accumulation of error across the sequence A - E - B - Fsharp ... A-octave (clockwise around the fifths cycle), and the range of errors amenable to correction on completion of the sequence. The number and accumulated magnitude of these <u>error possibilities</u> differs from note to note; and the total range of possibilities for each note covers all possible tuning errors for that note within the populations of, for example (a) all pianos, (b) all pianos in the experience of one individual, (c) all tunings of the same piano over time. During any one tuning we may suppose that the sequence of error is a '<u>random drift</u>' process alternating, in single error units, between sharp, flat, and cancelled error; the size of the unit error differs, of course, from tuner to tuner, being defined as the limit of the system or highest level of accuracy attainable.

An example of a random drift is included in FIGURE 17a: the sharp error from A to E is shown as being cancelled by the flat error from E to B, and the flat error from B to Fsharp is cancelled by the sharp error from Fsharp to Dflat; between Dflat and Aflat there is a further flat error, followed by a series of consecutive sharp errors across Eflat, Bflat and F. At G the magnitude of accumulated error stands, in relation to the initial zero of A, at two; and the subsequent errors fall in the area amenable to correction after the completion of the initial sequence by the arrival at octave A. Clearly, Harker's implication that each individual tuning will involve a steady accumulation of error to the sequence mid-point is not valid; he failed to consider that errors are as likely to cancel one another as to accumulate. Yet in the manner to be suggested here by which such errors may become manifest, a peaking of normally expected error differential at the mid-point (Eflat) is nonetheless apparent. And, in applying this concept in the following explanation of the key characteristic phenomenon, we should certainly acknowledge that Harker (1937) realised the same basic possibility first.

Before any inference can be made regarding the normal expectation of error within the possible range shown in FIGURE 17a, it should be pointed out that the error possibilities are not all equally probable. In the random drift from A to E only two possible errors can be made (either sharp or flat) and the probability of each is 1:2 (=0.5). In the tuning from E to B, however, there are four possibilities for error: (1) accumulation of sharp error, (2) accumulation of flat error, (3) cancellation of sharp error at zero, and (4) cancellation of flat error at zero. The eventuality of a zero error at B is thus twice as probable as either of the two possibilities for error accumulation. In fact, the distributions of possible error for each note follow a binomial curve, with the probability of zero error (relative to that at A) decreasing as the number of possibilities for error increases. All possibilities for non-correctable error, as shown in FIGURE 17a, may thus be quantified as in FIGURE 17b.

But we have dealt in FIGURES 17 so far with the possibilities associated with the clockwise tuning sequence alone (A to E to B to Fsharp ... to A-octave). The quantified error possibilities of the anti-clockwise sequence (A to D to G to C ... to A-octave)

Error Magnitude	A	E	B	F#	Db	Ab	Eb	Bb	F	C	G	D	A
+6							1						
						1		7					
+4					1		6		28				
				1		5		21		84			
+2			1		4		15		56		210		
		1		3		10		35		126		462	
0	1		2		6		20		70		252		924
		1		3		10		35		126		462	
-2			1		4		15		56		210		
				1		5		21		84			
-4					1		6		28				
						1		7					
-6							1						

Sequence of fifths

FIG. 17b Binomial quantification of FIG. 17a

Error Magnitude	A	E	B	F#	Db	Ab	Eb	Bb	F	C	G	D	A
+6							1						
						7		1					
+4					28		6		1				
				84		21		5		1			
+2			210		56		15		4		1		
		462		126		35		10		3		1	
0	924		252		70		20		6		2		1
		462		126		35		10		3		1	
-2			210		56		15		4		1		
				84		21		5		1			
-4					28		6		1				
						7		1					
-6							1						

Sequence of fifths

FIG. 17c Binomial quantification of possible error [anticlockwise sequence] are (FIG.17c) the reverse of those in FIGURE 17b. The totals of possible (non-correctable) error for each note (FIG.17d) are thus the sum of the corresponding totals for the clockwise and anti-clockwise sequences (FIGS.17b and c). The probability of each particular error magnitude for a note is equal to the ratio of its number of possible occurrences in the population of tunings, and the total number of occurrences associated for that note with errors of all magnitudes. In FIGURE 17d the frequencies of occurrence for each note, and their totals, are ranged vertically. Thus, the probability of a zero magnitude error for A is 925:925 (=1), and probability of any type of (greater) error is 0. The probability of a single unit of error (whether sharp or flat) for E is 463:926 (=0.5), and that of a single unit of error for Fsharp is 129:428 (=0.301). The probability of three units of error (relative to the initial zero) for Fsharp is, whether sharp or flat, 85:428 (=0.199); while P of four units of error for Dflat is 29:254 (=0.114). In this way the probabilities for each of the various error magnitudes are determined (FIG.17e) - though it should be emphasised that the error incurred in the tuning of any one note is only realised in its intervallic relationships with other notes; thus, for as long as they are considered in relation to single notes alone, such probability values have no manifest significance at all. Accordingly, we now examine the interval phenomena, prior to applying the probability values for individual notes in an estimation of the manifest error characteristics of the keys.

As phenomena in themselves intervals rarely attract any more attention from the musician than do single notes. Within a tonality context, however, particular intervals - between notes sounded

Error Magnitude

	A	E	B	F#	Db	Ab	Eb	Bb	F	C	G	D	A
+6							2						
						8		8					
+4					29		12		29				
				85		26		26		85			
+2			211		60		30		60		211		
		463		129		45		45		129		463	
0	925		254		76		40		76		254		925
		463		129		45		45		129		463	
-2			211		60		30		60		211		
				85		26		26		85			
-4					29		12		29				
						8		8					
-6							2						
(Total)	925	926	676	428	254	158	128	158	254	428	676	926	925

Sequence of fifths

FIG. 17d Totals of possible error [clockwise+anticlockwise sequences]

Error Magnitude

	A	E	B	F#	Db	Ab	Eb	Bb	F	C	G	D	A
+6							.016						
						.051		.051					
+4					.114		.094		.114				
				.199		.165		.165		.199			
+2			.312		.236		.234		.236		.312		
		0.50		.301		.285		.285		.301		0.50	
0	1.0		.375		.299		.312		.299		.375		1.00
		0.50		.301		.285		.285		.301		0.50	
-2			.312		.236		.234		.236		.312		
				.199		.165		.165		.199			
-4					.114		.094		.114				
						.051		.051					
-6							.016						

Sequence of fifths

FIG. 17e Probabilities of individual error magnitudes.

either simultaneously or consecutively - predominate over others; and it is at this level that the general musical interest focuses. The crucial ingredients of any tonality are its tonic, fifth, and (major or minor) third - this triad accurately represents the key in the absence of the other more redundant notes. Both melodically and harmonically these three notes are necessarily emphasised, for without any one of them the tonal context becomes ambiguous. Across the harmonies of their various chordal combinations pass the melodic configurations of all the notes in the key. When operating melodically, the more redundant notes of a key are known as the 'passing notes' - less time is given to them in the melody than to the notes of the triad. In the harmonic context of a key the lowest note of the triad may be any one of its members (third or fifth as well as tonic), and the triadic chord is thus 'inverted' in various ways. In each key, the predominant intervals are formed by the juxtaposition of the triadic notes, in all inversions, as follows:-

Basic triad - Tonic to Third, Tonic to Fifth, Third to Fifth;
1st inversion - Third to Fifth, Third to Octave-tonic, Fifth to Octave-tonic;
2nd inversion - Fifth to Octave-tonic, Fifth to Octave-third, Octave-tonic to Octave-third (= Tonic to Third).

The unique combinations are thus (1) Tonic to Third, (2) Tonic to Fifth, (3) Third to Fifth, (4) Third to Octave-tonic, (5) Fifth to Octave-tonic, and (6) Fifth to Octave-third. Each of the intervals featuring a third has two forms, major and minor; and, since the notes forming, for example, a tonic to third interval are the same as those of the third to octave-tonic, the number of unique intervals characterising the 24 major and minor keys is reduced still further to (1) Tonic to Fifth, (2) Tonic to Major Third, (3) Tonic to Minor Third, (4) Major Third to Fifth, and (5) Minor Third to Fifth.

The occurrence of octave, fifth, fourth and third intervals in even the most primitive cultures has already been referred to (CHAP.1); and as Boring points out (1942) these musical relationships between tones derive from the relationships between the aural harmonics. The sensations of harmony have been attributed to the interplay of overtones (harmonics) since the 18th century (Rameau, 1721; Tartini,1754; d'Alembert,1762), while the effects of differential beat frequency on the aesthetic responses to consonance and dissonance have been argued since Helmholtz (1862). It seems reasonable to suppose that the beats arising from error differential incurred in tuning the central notes of the keyboard may by certain individuals be finely discriminated; and that those arising in the tonal combinations that form a particular key will lend to it an unique and discriminable characteristic. Since the octave notes are traditionally tuned in perfect consonance with the central notes and, of course, with each other - a manoeuvre far less susceptible to error than the tuning of an imperfect interval - beat characteristics associated with the central notes will recur at each octave of the keyboard. Thus we will strive to determine the manner in which the various error possibilities may become apparent to the sensitive ear as <u>beat differential</u>.

When each note of the keyboard is sounded, the strings to other notes vibrate in sympathy: with A=440, for example, other A-strings reverberate also, for the 2nd, 4th, and 8th harmonics of the A (880, 1760, and 3520 cps.) are its octave multiples. The 3rd and 6th harmonics of a note form a fifth with the note and its octaves, and if a piano string is sounded (e.g. A=440) and suddenly damped, while the note a fifth above it is held down, the latter may clearly be heard. The 5th harmonic of a note (the major third two octaves above it) causes similar vibrations (fainter though still audible) in this example with the Csharp strings. Plomp (1966) has shown that the ear may detect at least five and not usually more than eight harmonics of a fundamental-tone; thus, if if is heard at all, the remaining harmonic (the 7th = G, the diminished seventh interval with A) will be heard to reverberate with other G-strings. Since none of the intervals in an equally tempered keyboard is mathematically perfect, the harmonics of a note and the strings vibrating in sympathy with them will not be precisely the same frequency, but will form a series of <u>mistuned consonances</u>; the rate of beats arising will depend on the extent of the mistuning. To one sensitive to such phenomena, other sources of beating may also be apparent - for the addition and subtraction of harmonics yield an infinite series of combination tones (Wever, 1941; Bryan & Parbrook, 1960; Plomp, 1966) and by subsequent additions and subtractions all manner of tones are produced in the ear (Ward, 1970). Of these, the first-order vibrations - between a note's harmonics and the strings forming its fifth, third and diminished seventh - are nonetheless the clearest.

On a keyboard equally tempered with total accuracy, the beat rate characterising these vibrations should be constant across the whole octave. By the present argument - which depends, of course on the hypothesis that absolutely perfect accuracy in tuning is impossible - the rate will differ characteristically from one note pair to the next. When two notes normally sympathetic to one another are actually sounded together, the beats between them are amplified; and since the two notes comprising the interval of a fifth, for example, have a large number of octave harmonics in common, the beats arising between them are clearly audible (v. below) - the 3rd and 6th harmonics of the lower tone, or tonic, beat against the 1st, 2nd, 4th and 8th harmonics of the upper. Indeed, the intervals yielding the clearest beats of all are precisely those most crucial in the representation of tonality; the notes comprising other intervals - the diminished second, major second, and major seventh, for examples - have no audible harmonics in common at all.

The characteristic beat frequency of two notes giving rise to audible beating in this way must be a function of the error difference between them, while the <u>magnitude of error differences</u> has already been represented as varying between different note pairs. For example, A, the standard/anchor-point of the sequence, may differ from an E by ±1 unit of error, from a G by ±2 error units, and from a Dflat by as much as ±4 units. On a single keyboard, at any one time, the actual intervallic error differences within these maximal limits will depend on the particular random drift of error in the previous tuning. In the general musical context, however, where notes are produced simultaneously on a variety of instruments, the strict accuracy of a note may also vary in the deliberate production - by rapid oscillations in lip-pressure and/or finger-positioning - of a 'vibrato'. The overall accuracy of a note produced by a non-keyboard instrument, and of its intervallic relationships with other notes, depends on the accuracy of the internal pitch standards on which the musician's judgments are based. Recent evidence regarding the scaling of these internal standards (summarised by Ward,1970) suggests that the same normally expected error differential across the octave is likely to occur on keyboard and non-keyboard instruments alike.

For the investigations have shown that the internal pitch scale used by musicians in playing their instruments corresponds not to the mathematical ideal as one might suppose, but to the equally tempered scale (ET) that has held sway for so long.

> "Undoubtedly, the surface has been barely scratched in the study of intonation in performance. However, it is now clear that, on the average, the internal scale of musical pitch used by musicians corresponds fairly closely to ET ... (possibly owing) to the extensive experience all musicians have had with the universal piano." (WARD,1970).

On hearing a Pythagorean interval (mathematically perfect, as on an untempered keyboard) musicians will ruefully acknowledge that it "sounds purer" than the tempered version to which they are accustomed - yet, as Ward's evidence indicates, they will nonetheless continue to operate by their internal equitonic scale in subsequent performance. String quartet players, similarly, will agree that their aim in performance should be to avoid tempered intervals; for a violin or 'cello - unlike the piano - produces a continuous frequency range for sub-division as the ear alone dictates. Yet, in their customary roles as soloists to keyboard accompaniment, and as orchestral accompanists of keyboard soloists, even violinists must operate on an equitonic basis in order to avoid the unacceptable pitch contrasts that prompted the development of Equal Temperament originally. The same constraints apply to the wind player and to the singer. And, basing it squarely on the assumption by Ward (above) that the internal equitonic scale may derive from "the extensive experience all musicians have had with the universal piano", we now offer the prediction that the range of hypothesised error probabilities in production of each note will be - for all musicians and, consequently, on all instruments - the same as given for the keyboard, as in FIGURE 17e.

In the simultaneous contrast of notes produced according to the rules of Western harmony, from any musical source, we would thus infer that all combinations of erroneous intonation are possible. In the scheme of FIGURES 17, we have already argued that the range of error possibilities may vary between notes, with (in the populations of all possible tunings) a greater number of pairings available between, for example, the A and different tuning possibilities for Dflat than between A and G; an Eflat may differ from an Aflat by as much as eleven error units. The error difference between one pair of tuning possibilities (e.g. a C that is sharp by three units, and the G that is flat by two) may be identical to that of another pair (e.g. the Aflat=+1, and Eflat+-4). However, the actual probabilities of the two pairings may differ; and, taking both parameters into account, a measure of the <u>probable beat characteristic</u> (PBC) of each possible pair of notes occurring simultaneously on more than one instrument is given by the product of the error difference between them (modulus error value, MEV) and the joint probability of their simultaneous occurrence (JP). The PBC of the fifth interval between (A=0) and the E that errs by one unit to sharp (E=+1) is thus given as follows:

$$\begin{aligned} PBC_{(A=0)\mathrm{to}(E=+1)} &= MEV_{(A=0)\mathrm{and}(E=+1)} \times JP_{(A=0)\mathrm{and}(E=+1)} \\ &= \mathrm{Mod}(0-+1) \times (1 \times 0.5) \\ &= 1 \times 0.5 \\ &= \underline{0.5}. \end{aligned}$$

Since E may err in the opposite direction also (=-1, flat), the total <u>beat quotient</u> (BQ) for both possible tuning combinations of A and E will be equal to the total of the PBC quantities associated with each individual combination:

$$\begin{aligned} BQ_{(A\ \mathrm{to}\ E)} &= PBC_{(A=0)\mathrm{to}(E=+1)} + \\ &\quad PBC_{(A=0)\mathrm{to}(E=-1)} \\ &= (MEV_{(A=0)\mathrm{and}(E=+1)} \times JP_{(A=0)\mathrm{and}(E=+1)}) + \\ &\quad (MEV_{(A=0)\mathrm{and}(E=-1)} \times JP_{(A=0)\mathrm{and}(E=-1)}) \\ &= (\mathrm{Mod}(0-+1) \times (1 \times 0.5)\ ) + \\ &\quad (\mathrm{Mod}(0--1) \times (1 \times 0.5)\ ) \\ &= (1 \times 0.5) + (1 \times 0.5) \\ &= \underline{1}. \end{aligned}$$

Between E and B more tuning combinations are possible: (1) E=+1 to B=+2; (2) E=+1 to B=0; (3) E=+1 to B=-2; (4) E=-1 to B=+2; (5) E=-1 to B=0; (6) E=-1 to B=-2. Between B and Fsharp the possibilities are more numerous still (= 3 x 4 = 12); and by summing the probable beat characteristics of all possibilities for each interval we obtain a set of characteristic, normally expected beat quotients denoting relative beat qualities of that interval across the twelve-note scale. Where NTC is the <u>number of possible tuning combinations</u>, the equation by which the beat quotient of any interval (J to K) may be calculated thus becomes

$$BQ_{(J\ \mathrm{to}\ K)} = \Sigma_{NTC(JK)}(MEV_{(J\ \mathrm{to}\ K)} \times JP_{(J\ \mathrm{to}\ K)}).$$

The beat differential for each of the five key-characteristic intervals (above) is given in TABLE 19.

TABLE 19.

Beat differential of the key-characteristic intervals.

	Tonic to fifth	Tonic to Maj 3rd	Tonic to Min 3rd	Maj 3rd to fifth	Min 3rd to fifth
C	2.171	1.794	2.622	1.624	2.265
G	1.624	1.718	2.419	1.624	2.063
D	1.000	1.794	2.157	1.794	1.858
A	1.000	1.853	1.794	2.157	1.794
E	1.624	2.063	1.624	2.419	1.718
B	2.171	2.265	1.624	2.622	1.794
Fsharp	2.583	2.516	1.794	2.798	1.853
Dflat	2.798	2.630	2.157	2.798	2.063
Aflat	2.835	2.516	2.419	2.622	2.265
Eflat	2.835	2.265	2.622	2.419	2.516
Bflat	2.798	2.063	2.798	2.157	2.630
F	2.583	1.858	2.798	1.794	2.516

The interval of tonic to fifth characterises both versions (major and minor) of a key. The beat differential of the fifth intervals is plotted in FIGURE 18a. Its close resemblance will be noted to both of the brightness effects elicited experimentally (FIGS.9c and 16a), though in FIGURE 9c the effect was reversed owing to the arbitrary expression of the 'bright' associations by positive scores and the 'dark' ones by negative. As the beat differential of fifth intervals is more like the main brightness

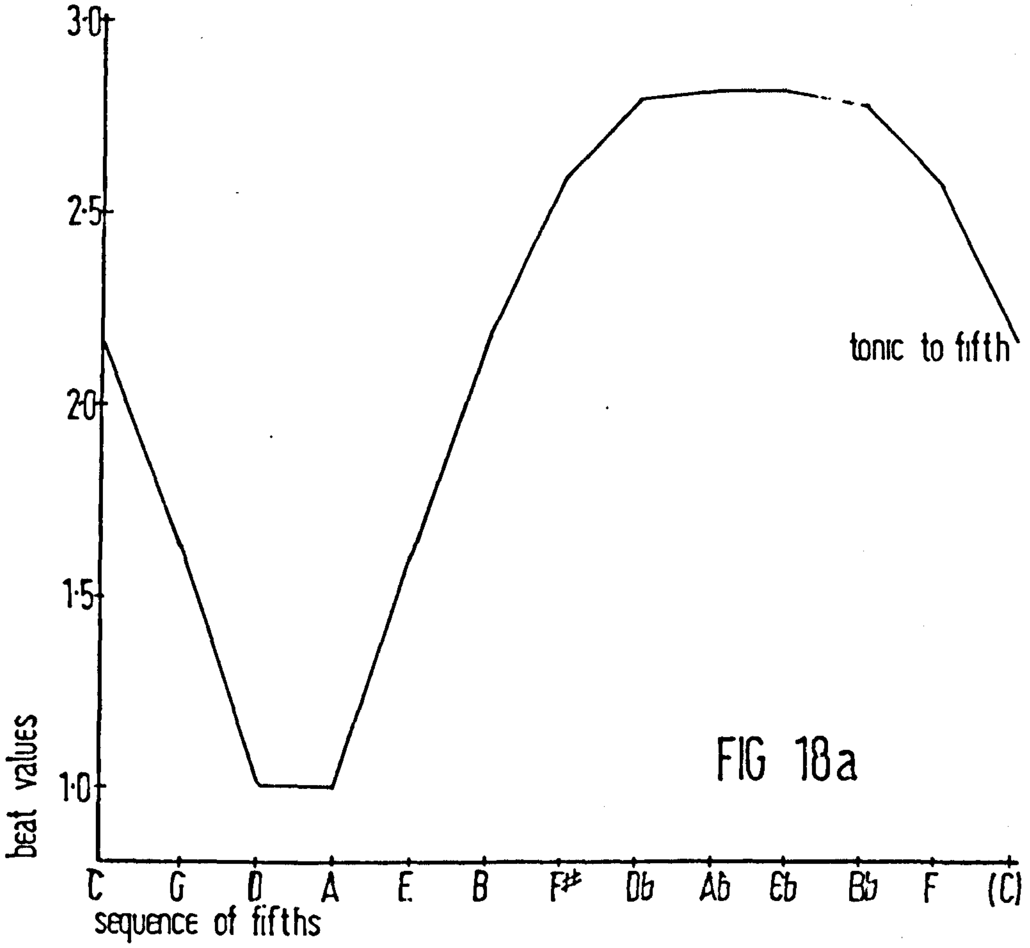


FIG 18a

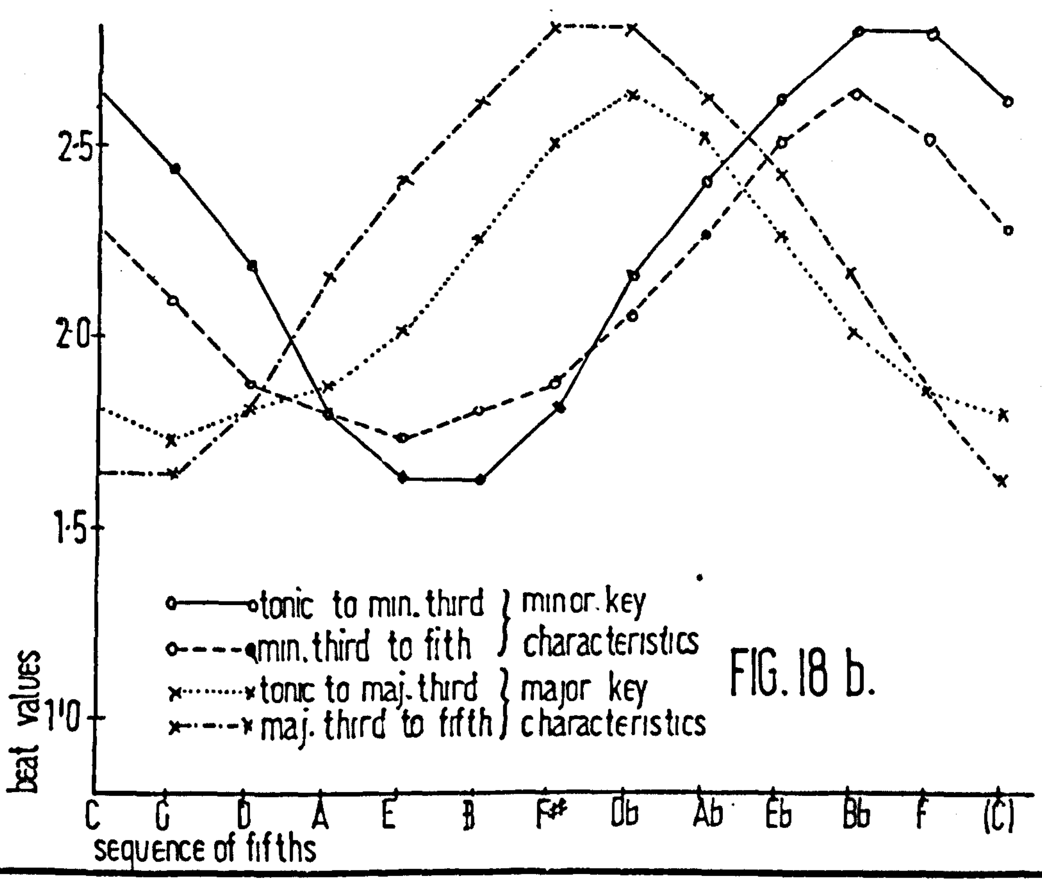


FIG. 18 b.

FIGS. 18 Beat differential of the key-characteristic intervals effects than are the differentials of other intervals (below), we tentatively conclude that the main brightness effects isolated in the chromaesthetic, intersensory integration, and Absolute Pitch contexts discussed earlier may primarily derive from a sensitivity by various individuals to the beat differential arising in fifth intervals (by the above process) as a result of error incurred in the approximate intonation of equal temperament. In a few informal sessions at the well-tuned Steinway Grand of Sheffield University's Music Department, the writer has played numerous simultaneous fifths, asking musicians to concentrate on the frequency of the beats arising from them. The observations support the present concept of beat differential neatly: a D/A combination was described by one musician as "bare and bleak ... hardly any beats at all", while the veritable blur of beats characterising the central Aflat/Eflat combinations was apparent to all, with surprise expressed that they had not noticed these qualities previously.

(Indeed, these observations imply even less accuracy on the piano tuner's part than we have been ready to allow. The process by which such qualities are translated into terms of colour, brightness, etc. will be discussed in the NEXT SECTION).

As well as the primary effect of fifth differential, other (secondary) effects may occur. In FIGURE 18b, the beat values differentiating the major and minor thirds of each key are plotted - general resemblances between the curves characterising the major keys, also between those of the minor keys, are apparent, while the phase separation of major and minor along the FIGURE's abscissa amounts to a minor third. This observation reflects the fact that the notes of a major key and those of its 'relative minor' (a minor third removed) are virtually identical; and it recalls the observation by Sabaneev (1929) that the colour associations of major and minor keys which are related in this way are often the same (cf. the associations of the subject JKM: FRONTISPIECE and APPENDIX II). Further (composite) effects may also be determined, in which the differentials of each interval are combined in, for example, the proportions in which they typically occur in the musical repertoire. However, this manoeuvre requires a statistical analysis of the repertoire somewhat beyond the writer's present scope. The rigorous test of these hypotheses using experimental stimuli will demand further weighting in the calculation of effects according to (1) the strength of each harmonic in the stimulus notes - this will vary with timbre differences - and (2) the ability to distinguish harmonics as it varies between individuals.

At this stage, however, and with particular reference to the key characteristics phenomenon, we are content to present a basic hypothetical rationale. It is grounded on a number of assumptions which, untested, deny it the status of a theory. The prediction of differential error probability in the musician's internal pitch scale, for example, needs to be tested by comparisons of the accuracy thresholds for each note in matching and identification tasks. But the rationale is posed nonetheless, in the knowledge that none of the empirical evidence for the audio-visual phenomena reported earlier in any way relies on it. If the demonstration of a hypothetical beat curve resembling the sinusoidal effects established empirically can suggest any subsequent approach to these phenomena then it is worthwhile.

5.2 IMPLICATIONS FOR ABSOLUTE PITCH AND SYNAESTHESIA.

In CHAPTER 3 we saw that the identification of tonality depends initially (Corso,1957) on the ability to extract from a group of notes information regarding their relationship to each other and to the tonic; once the tonic has been isolated the other notes may be considered in the scalar sequence that they form in relation to it. The confusion often reported by chromaesthetes and AP possessors alike as to whether their associations are with a note in isolation or with the major key based upon it, suggests that, at the stage where the relationships between the notes of a key and its tonic are identified, the characteristic (or 'chroma') of the key as a whole may come to be associated (in the highest levels of AP ability) with the tonic also. Given the ability to make fine discriminations of beat frequency, the differential beatings may thus be encoded for each tone, affording it an unique quality - hence the concept of 'tone-chroma'. While the AP capacity to identify the tone in isolation may depend on the recognition of this 'chroma', the ability to reproduce it by singing/humming/etc. will rely on the quality's permanence in the internal reference scale. In every branch of human learning we encounter Bartlett's 'effort after meaning', and the permanence of an item learned depends on the number of meaningful connotations it can evoke. Since the general vocabulary is rather restricted with regard to the connotations of single tones, it is not surprising that the AP possessor should either devise his own terms or borrow them by some rationale from other sources.

The same point was argued in CHAPTER 2; we concluded that the synaesthetic response is a translation of meaningful stimulus or imagery qualities (in the absence of an adequate vocabulary for their expression) into more usually communicable terms. As the mechanism for translating material synaesthetically seems available to most sections of the population (CHAP.2), we may now predict that the AP population will use it with particular reference to tone. That the terms primarily identified with visual sensation are particularly meaningful in relation to auditory stimuli has also emerged; and, indeed, of the 29 AP claimants that have been studied by the writer, 23 of them (=79%) report some form of tonal synaesthesia, and all of these make some reference to sensations of the visual modality; 12 of these (=41%) associate the tones with specific colours. These figures compare favourably with the various estimates of synaesthetic imagery in the general population reported in CHAPTER 2 - of children 43%, of eidetics 41%, and of all other populations between 28 and 7%. Of course, a chromaesthete makes use of a range of qualities already meaningful to the general population. But, in order to code his tonal experiences, an AP possessor is not obliged to become a chromaesthete: as indicated, he may devise his own terms for the qualities he perceives. By the general populace such terms may be regarded as total abstraction ("Eflatness", for example); and, though perfectly meaningful in the internal coding system of the individual, they may not exist at a verbal level at all. In view of the apparent tendency of extraverts to report more meaningful synaesthetic imagery than introverts (Pickell, 1937) we might predict that the Extraversion scores of AP subjects should differentiate those among them who express tonal quality in terms of (meaningful) colour from those who do not. At the time of writing, 19 of the 29 AP subjects mentioned have completed (on separate occasions) both forms of the EPI. The correlation between E scores on the two forms was +0.773 - lower than that of the N-scale(r = +0.816) - cf. Eysenck's 1964 estimates: (E) +0.757 and (N) +0.811. A low E score was defined as less than 10, and a high one as greater than 12; Fisher's exact probability test was applied to the observations within the following 2 x 2 matrix:

(1) Low-E / Chromaesthetic; (2) High-E / Chromaesthetic;
(3) Low-E / Non-Chromaesthetic; (4) High-E / Non-Chromaesthetic.

The prediction was supported: on both forms of the EPI the number of AP subjects in Groups (2) and (3) was greater than those in Groups (1) and (4); the observations within each cell are given in TABLE 20. The difference in the matrix pertaining to Form A scores was not significant (P=0.08), though that of Form B was significant at the 0.03 level.

The inter-relation of Extraversion and Neuroticism (in EXP/D and previous investigations: CHAP.4) will be mentioned again later; as the nature of their interaction in relation to the present work is as yet uncertain, it will require further investigation before definite conclusions with regard to the coding process in AP may be reached. Thus, the discussion of the views now expressed will be primarily restricted to their implications for the phenomena that have already been reported in the earlier chapters. The predominance of visual qualities in the imagery of tone will occasion references to the 'visual ear': though, as the previous paragraph indicates, an AP or synaesthetic individual may relate his percepts to qualities of any modality or to more personal concepts altogether.

TABLE 20.

Categorisation of AP claimants regarding Extraversion scores (EPI, both forms), and claims to chromaesthesia.

	CHROMAESTHETIC?		Fisher's Exact Probability
E SCORE	Yes	No	
High	5	1	P = 0.08
Low	3	6	(EPI Form A)
High	6	1	P = 0.03
Low	2	6	(EPI Form B)
High	11	2	P = 0.003
Low	5	12	(Forms A+B)

(N.B. High E = EPI > 12
Low E = EPI < 10).

In relating AP sensitivity directly to the extraction and recognition of 'chromal' qualities arising between notes, we gain also an explanation for the phenomena attributed by Bachem (1948) to 'chroma fixation' in genuine AP (CHAP.1). The observation of a limit at app. 5,000 cps. beyond which chroma disappears though tone-height is still apparent, is reasonably explained by the fact that only the 2nd and 3rd harmonics of a 5,000 cps. fundamental are within the normal auditory range; and, since these frequencies are of 10,000 and 15,000 cps. respectively, they are likely to be very faint anyway - so they provide notes with little or no audible beat differential, and no tone chroma. Indeed, by Bachem's calculations, AP judgment accuracy begins to wane at app. 3,500 cps., and since a fundamental of this frequency has at the very most only five audible harmonics, we may infer that the absolute ear requires at least five harmonics for consistent accuracy in such judgments. Of course, the lower the fundamental, the greater the number of audible harmonics, and the more 'saturated' each chroma becomes; but if a note is too low, once again it becomes difficult to differentiate the chroma. Though Bachem was unable to specify the exact threshold at which lower fixation takes place, it is generally agreed (by AP subjects of the writer) that low-note judgments cease to be reliable at app. 100 cps.

In explaining the lower level of chroma fixation, we clearly cannot use an identical argument to that applied at the upper level, for notes of 100 cps. and less have an abundance of harmonics within the auditory range. But we may nonetheless explain it on the same basis, whereby chroma is seen to originate in differential harmonic beating. It is first of all necessary to consider the nature of the critical band within which beats between two frequencies occur. The various estimates of bandwidth (Feldtkeller & Zwicker,1956; Greenwood,1961; Tobias,1970) show that it increases with the ascent of the frequency spectrum from low to high. However, examination of the best approximations to critical bandwidth that are currently available (by Scharf,1970) shows that the rate of increase differs from that of the frequencies of the musical scale. Since the relationship between the musical scale and the frequency spectrum is logarithmic (CHAP.1), a musical interval (I) is given by the difference between the logarithms of the higher frequency and the lower;

$$I = (\log H) - (\log L) = \log (H/L).$$

The frequency of the higher note in an octave is twice that of the lower note, and the interval is thus log 2. Since there are twelve semitones in an octave, one semitone (S) is equal to (log 2)/12. The number of semitones (N) in any interval is I/S. Therefore

$$N = \frac{\log (H/L)}{(\log 2)/12} = \frac{12 \log (H/L)}{\log 2}$$

(which may be further simplified to 12 times the log to the base 2 of H/L. The formula may be tested using the frequencies for notes in the tempered scale given by Revesz (1953,p.252). N.B. An error in his table: Ratio of D to C is 1.12246 and not 1.22246).

In this way we may calculate the semitonal distances spanned by various critical bandwidths. Scharf (1970,p.162) assesses 24 bandwidths; and their conversions by the above equation into semitones are given in TABLE 21. From FIGURE 19 it is evident that at very low frequencies (less than 200 cps.) the critical band of each central note spans more of its neighbouring notes than at any other level in the range. Intervals that never occur within the critical band at higher levels will now do so; and since frequencies within the bandwidth tend to be judged as dissonantly related (Plomp & Levelt,1962), the character of certain consonant intervals (the fifth, fourth, and third in particular) will become less than usually satisfactory from the musical point of view.

TABLE 21.

Conversions of critical bandwidth estimates (Scharf, 1970, p.162) into semitones.

Lower cps	Upper cps	Bandwidth		Central cps
		cps	semits	
∞	100	∞	∞	50
100	200	100	12.00	150
200	300	100	7.02	250
300	400	100	4.98	350
400	510	110	4.21	450
510	630	120	3.66	570
630	770	140	3.47	700
770	920	150	3.08	840
920	1080	160	2.78	1000
1080	1270	190	2.81	1170
1270	1480	210	2.65	1370
1480	1720	240	2.60	1600
1720	2000	280	2.61	1850
2000	2320	320	2.57	2150
2320	2700	380	2.63	2500
2700	3150	450	2.67	2900
3150	3700	550	2.79	3400
3700	4400	700	3.00	4000
4400	5300	900	3.22	4800
5300	6400	1100	3.26	5800
6400	7700	1300	3.20	7000
7700	9500	1800	3.64	8500
9500	12000	2500	4.04	10500
12000	15500	3500	4.43	13500

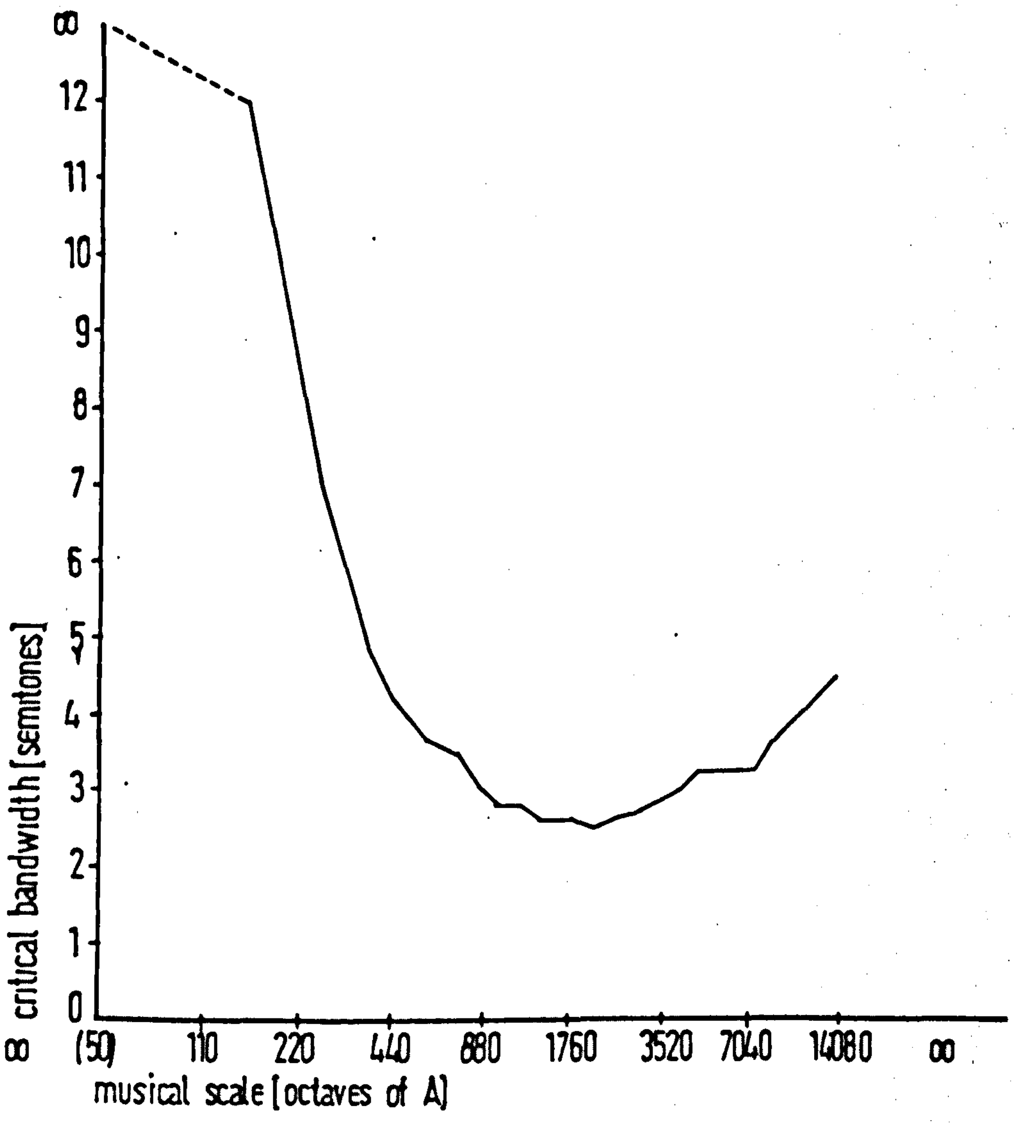


FIG. 19 Critical bandwidths [semitones] across auditory range

That at least two composers (Bach and Dvorak) avoided using these intervals at low frequencies in their work has been shown by Plomp & Levelt (1962), moreover, their frequencies of usage vary in direct relation to the critical bandwidth throughout the musical range. In the present context we would predict that the character of single notes will alter as well as those of intervals - a low note of (e.g.) 150 cps. beats not only against the harmonics of other notes in the differential manner that we have discussed, but also against the unusually large number of neighbouring semitones that fall within its band; and the beat differential that would otherwise afford the note a chroma is thus obscured. At one octave higher in the range (300 cps.) the abnormal beating has diminished substantially (FIG.19), and the chroma becomes easier to detect.

By comparison of FIGURES 9c, 16a and 18a, it has already been suggested that 'darkness', as an attribute of the cyclic scale of tonal quality, is related to the notes normally characterised by the greater levels of beat magnitude; similarly we now recall that low notes per se are associated with darkness too - so we have a reason for arguing that synaesthetic responses to tone-height and tone-chroma may derive from the same basic mechanism. Linear beats and cyclic beats have different sources, but the means by which they are perceived and encoded by the visual ear may be identical. The manner of their encoding - why greater beats should come to be equated with darkness, and lesser beats with brightness - is not clear; this will relate to our greater knowledge of the ways perceptual and judgmental dimensions are processed at the neural level. But when it does become clear the implications of this hypothesis may prove to embrace the synaesthesias of other modalities, and may aid in our understanding of the aesthetic response in general (below). Other problems - the cases of 'paracusis qualitatis', for example (CHAP.1), and the phenomenon that several AP subjects have reported to the writer, namely a tendency to judge notes as gradually sharper in pitch with advancing years - these too remain for further study.

To test the indication that it is indeed the particular brightness attribute of a colour rather than its hue per se that primarily determines its interaction with the various tones, a brief questionnaire study of 'key-brightness' was made (APPENDIX III) using groups of Non-AP musicians (N=28) and AP claimants (N=15). Their responses to each key (major and minor) were made on a semantic differential gradation from (1) Bright to (9) Dark; a significant difference was found between their responses to major and minor keys, though none between the two subject groups themselves. (The results of this supplementary study are fully detailed in the APPENDIX). Once again the brightness curves that were isolated fluctuate sinusoidally across the sequence of fifths with their customary peaks,i.e.for bright and dark. The similarity between ratings of AP and Non-AP groups - in both this situation and the similar situation of EXP/B - is not necessarily surprising; for significant contributions to the Non-AP effects may well have come from chromaesthetes aware of the particular stylistic uses to which the keys have been put by various composers. The possible origins of a synaesthetic response of this sort, and the ways in which it may be perpetuated by translation into other aspects of musical style (CHAP.2) are endless. Using the anecdotal report as evidence, we may not even be sure that individual composers were sensitive to tone-chromal characteristics - for it is equally probable that they too merely detected, and translated, the characteristic usages of chroma-sensitive composers more previous still. Nor should we suppose that Brightness may be the only population determinant of a chromaesthetic translation: the associations with mid-bright keys (FIG.8) suggest the agency of various sub-factors consistent with the brightness rationale though ultimately explicable at a level beyond it. For instance, F, the traditional key for pastoral music, is now predominantly associated with Green; while C, the 'martial key', is commonly considered either Red, or (no doubt because it contains no black notes) White. Associations such as these may be perpetuated in the musical tradition quite consciously; AP and Non-AP musicians alike claim the same associations with equal conviction, and the overt abilities of Non-AP chromaesthetes may give no hint of tone-chromal sensitivity otherwise.

However, that the AP and Non-AP groups should show striking similarities in the audio-visual structures elicited by EXP/D is surprising indeed; it was expected that only the AP subjects would have the tone-chroma sensitivity necessary to promote these interactions. Let us first re-examine the interaction structures of EXP/D more closely. The clusters of scores in the various significant effects (FIGS.16) are invariably negative. Where the main cluster occurs (as in FIG.16b) at the notes identified in EXP/B as 'usually dark', we may interpret the visual quality that interacts differentially with the tones in that effect as 'negative darkness' or 'brightness'; similarly, the negative clustering of integration values at the 'usually bright' notes leads to an identification of an 'inhibitory brightness' effect representing interactions between the darkness qualities of the two modalities. That the scores of both subject groups should yield these interactions implies that Non-AP subjects may detect the tonal 'brightness/darkness' qualities as well as the AP subjects. For this notion the explanation is perhaps as follows.

Genuine AP, as defined in CHAPTER 2, has been thought to depend on experience from an early age of the notes as '<u>individual phenomena</u>' rather than as members of the low-high configurations that form melody. The most puzzling aspect of AP, as Ward points out (1970), is not that it should exist at all but that so many people should not have it. If AP indeed rests on a sensitivity to beat frequency, its rarity may seem even more curious, since beat sensitivity is clearly an important pre-requisite of the musical ear. Therefore, if Non-AP musicians are indeed sensitive to chromal qualities - as both EXPS/B and D would suggest - what might prevent them from using the information in the way that AP possessors do? It is possible that the perception of notes and their simple combinations as individual phenomena, and the subsequent reference to the qualities characterising them, may be prevented by the constant variations of the melodic and harmonic contexts in which they occur. The perception of a note as low in the range (a position denoting darkness on the linear scale) will mitigate with the fact that in the cyclic scale it may be an A and thus bright. If it is a high Eflat the attributes of brightness and darkness that may thus be evoked will again conflict, and the normal attention to the note's position in the linear (melodic) sequence will overwhelm any tendency to code it by the darkness cues arising from its beat value as an Eflat. So, unless the earliest musical experiences have tended to emphasise the latter (cyclical) cues, the customary musical juxtapositions in the linear range will cancel them. The early emphasis on the absolute cues is necessary in order that they may be reconciled with the relative cues that music later emphasises. Thus the cyclic (beat) information may be gleaned in any musical situation in which the child is not led to concentrate on melodic (consecutive) patterns rather than on harmonies; and chordal aural tests or presentations of random note combinations on the household piano are clearly favourable constituents of the situation in which AP may consequently develop.

Brady's 'fixed-scale mechanism' of AP (CHAP.2) rests on an early childhood basis similarly, though his theory (in which the tones supposedly acquire a quality from the fact that they were initially heard in one key only) is limited in its application to naturally occurring AP by the frankly admitted fact that his "entire mechanism collapses on hearing a fragment (a few seconds) of music played in a key other than C", the key on which the mechanism was fixed. In all respects other than this, Brady's theory (1970) satisfies the Bachem definition of genuine AP (CHAP.1) quite adequately: the fixed connotations of each note in its customary position in a particular key provide an internal reference scale on which absolute judgments totally independent of external cues may be made. Were it not for the inbuilt fallibility of Brady's mechanism with respect to all but the fixed scale, it would clearly resemble, in its extraction of information from interval comparisons, the process suggested in the previous section. The ability predicted by the beat differential hypothesis fulfils all of Bachem's criteria; its additional implications for the theory of chromaesthesia render it doubly attractive. And, furthermore, that the internal reference cues are regarded as deriving from the structure of the scale about its central A, effectively deals with the previously awkward fact that qualities seem to have remained much the same over the past 150 years though the absolute frequency values of the scale have varied. The British A=440 standard, as mentioned earlier, has been fixed since 1939; nonetheless, fractional differences (less than a semitone) between the modern tuning standards of Britain, the Continental countries, and U.S.A. are still encountered (Grove, 1954). These facts must certainly be taken into account in any theory of naturally occurring AP, or tonal synaesthesia, and a margin for readjustment to different standard scales be permitted to even the most 'genuine' of AP mechanisms. Not only do these differences occur between countries, for any two pianos are virtually certain to differ by a few cycles at least (this is possibly a further reason why AP is not more commonly possessed). The experiences of the writer and his other AP subjects do indicate the <u>flexibility of the absolute reference scale</u> - that a certain degree of tolerance is a necessary feature of the system. On occasions, for example, the writer is obliged to play a piano that is flatter than the standard 'concert' pitch by a full semitone. At first considerable difficulties arise, for the notes "look normal" but "sound wrong" - their F frequencies are approximately the same as more customary E's. After a while, however, the conflict is resolved and the F's sound like F's after all. The effort involved in deliberately transposing sheet music into a different key is similarly gruelling; for the mental image of a note expected is at odds with the actual sound of the note that must be played. Indeed, singers and musicians who play transposing instruments occasionally report that they have lost (or "broken down") their AP sense by dint of constant transpositions between one key and another, and with no time to adjust to the absolute values of either; the only way they can cope with these demands is to develop their relative pitch ability, but in the concentration on relative cues the absolute qualities are overwhelmed.

The nature-nurture argument of AP (CHAP.1) is reconciled by the supposition that, while the mechanism which senses the absolutist qualities of equally-tempered tone is innate, the opportunity to encode these qualities is separately determined by environmental factors. Of course, a 'tone-deaf' person may be considered to lack even the former capacity, though, in the population of those who do possess it, it is likely that different levels of genuine AP occur. (Whilst this opinion is in accord with the classical learning view of AP, it differs from it by placing greater emphasis on the utilisation of absolute rather than relative cues). A final illustration is here in order: in a discussion of AP between the writer and the composer Antony Hopkins, it transpired that the latter regularly finds himself able to anticipate a familiar radio or television signature tune in the correct key. To the AP possessor experiences of this sort are common, and the (AP-possessing) writer had amused himself by correctly anticipating the BBC-TV 'Top of the Form' signature tune the night before. He mentioned this to Mr. Hopkins, who immediately whistled the same tune in the key of F major. Since Antony Hopkins denies possessing AP himself he was unable to verify whether this was the correct key or not, while the writer could confirm that it was. The writer has been informed of similar incidents quite often; such moments of unexpected accuracy on the part of a Non-AP musician may well be random, yet they are often accompanied by a spontaneity and conviction that takes the musician completely by surprise. That he cannot subsequently develop a consistently accurate AP capacity may be due to the manner in which he attempts to - by playing to himself notes in sequences that emphasise conflicting relative cues at the expense of the absolute quality. But the occurrence of various levels of AP ability is nonetheless accommodated by the present hypothesis - e.g. the violinist's memory for his A, and the pianist's for Middle C. The above anecdote implies the existence of a level intermediate to a 'standard pitch' and the AP ultimum; and further research may serve to relate these different levels (in the terms we have suggested) to, for example, individual differences in beat sensitivity.

The emphasis in stimulus presentation on the relative cues no doubt explains the linear basis of associations in EXP/A as well as EXP/C: subjects who did not possess AP attended to the information of the relative scale in being required to equate the tones with colour. In EXP/B we noted an association scheme based on the more subtle cyclic tonal sequence: on the latter basis, the associations with a note and its octave are predicted to be the same, whereas on the linear basis they differ. In EXP/C the two bases for colour-tone association were considered to have been reflected in two particular intersensory interaction effects. It seems that a pre-stimulus (whether auditory or visual) promotes a positive or negative 'set' depending on whether it is compatible or incompatible on some rationale with the heteromodal judgment stimulus. The set in turn influences - in various fashions connected with the personality dimensions - the time taken to make the judgments required. Pitch differences among the stimuli used in EXP/C were of a diminished fifth (6 semitones) and Non-AP subjects gave interactions suggesting the linear associations of EXP/A. In EXP/D, however, different stimuli were divided by one semitone only: in this situation all subjects (AP and Non-AP alike) gave interactions suggesting a sensitivity to cyclically based qualities. In the next section this fact, and the various other questions raised by EXP/D (effects of Extraversion vs. Neuroticism, Target vs.Judgment scores, and the anomalous interactions), will be discussed, and the evidence for the above hypotheses further evaluated.

5.3 IN WEIGHING THE EVIDENCE.

From the argument that tone-chroma can be perceived by musical subjects other than those who are able to use it for AP judgments, and from the observation of different types of Non-AP interaction (linear and cyclic) in the different judgment situations of EXPS/C and D, we may proceed to suppose that in EXP/D the Non-AP subjects were presented (possibly for the first time in their lives) with an intensive series of tones as individual phenomena. The progression of notes from low to high occurred in semitones only and was thus minimal; as a result of their continual concentration upon, and assessment of, these stimuli, it is possible that the sensitivity of these musicians to the absolute qualities of the notes was given an unique opportunity to emerge. It has been argued that the deliberate acquisition of an AP conforming to Bachem's criteria (CHAP.1) may never be achieved by concentrating on notes from a wide range at once, for in such a context their absolute qualities will be concealed by the low-high qualities of their relative juxtaposition. By specific attention to notes from a narrow range, however, one may well consolidate a knowledge of their individual qualities that will remain and even dominate the more usual interest in music's melodic features. Accordingly, we may admire Bachem's enthusiastic description of the "luminosity and brilliancy" in music that may only be appreciated by an AP sensitivity to tonality characteristics. And, in regard to the development of this perceptual style, we are reminded of Sergeant's evidence (1967) that the earlier a child begins musical training the more likely it is to have AP in later life - of those of Sergeant's subjects who began training between

2 and 4 years of age, 92.6% apparently possessed AP, whereas of those who had been over 14 yrs. at onset of training none possessed it.

An explanation for the tentative emergence of AP effects in the analysis of Colour/Target-note interactions (while those of the Non-AP group occur in the Judgment dimension) is as follows. Once a Target has been specified, AP subjects are able to recognise it by the match with their internal reference scale; they may now refer a Judgment tone to the internal coding of the Target, rather than relying on their being able to detect the relative attributes of consecutive Judgment tones alone. But the accuracy of their judgments nonetheless relies on the retention of their internal Target, and by concentrating on it they render it liable to the interactions with colours they have perceived simultaneously. As most Non-AP subjects seem incapable of holding a note in mind at the level of accuracy demanded by this task, and for the length of time required, they were obliged to concentrate to a greater extent on the Judgment stimuli, causing these to interact with the colours accordingly. Experimental support for this admittedly intuitive analysis has been provided by Fitter (unpublished data, 1970): two AP claimants and four non-musicians were presented with a pair of tones and then required todetect whether or not they subsequently occurred at near threshold level in white noise. The AP subjects recognised the notes immediately as a C and a G, and seem to have concentrated on their internal representations of C and G as an aid to the task at hand - for in so doing they failed to perceive the Eflat tones that were surreptitiously included. The Non-AP subjects, on the other hand, perceived all three notes at equivalent levels of accuracy.

The anomalous interactions of EXP/D would seem to be related to beats arising between the notes in question and the hum from the projector. Identified as a frequency between A and Bflat (closer to the A), the hum is likely to have given rise to beats not only with the A and Bflat stimuli but with their fifths and fourths also. By the equation of greater-beating notes with darkness, one may come to understand the irregular interactions between each of these notes and the darker hues. By contrast, the notes judged together with them (Aflat and B) may be expected to become phenomenally brighter than they would have been otherwise; and the anomalous Aflat interactions are in fact both identified, in the context of the structures with which they interfered, as "too bright". B, in being a bright tone anyway, interacted in the usual direction. And, stemming from overtone beats, the remaining two anomalies (D and E - both "too dark") are in accord with the above explanation also.

Concerning the influence of Neuroticism and Extraversion on the interactions, several possibilities have already been mentioned (CHAP.4). The connections between neuroticism and higher sensory acuity (Nebylitsyn et al.,1960) indicates the possibility that neuroticism in this task, also in EXP/C, is a correlate of the initial sensitivity to the differential beat frequencies underlying tone-chroma, and as such will be influential on their interactions with colour. But we should not infer that the ability to code and utilise this information in AP itself relates to Neuroticism similarly - this we have already attributed to the early experiential factor, and, in some measure, to the Extraversion component. The latter scale has been found to correlate with performance on perceptual tasks by other investigators (CHAP.4). According to Eysenck's theory, the augmentation of a stimulus by introverts and its reduction by extraverts relates to individual differences in the rate at which these subjects accumulate reactive inhibition. The correlations between E scores in EXP/D and the direction of the intersensory effects (facilitation and inhibition), may possibly be explained on just such a basis, though in view of the interplay between N and E scores in this experiment it would be unwise to speculate further in this respect prior to further investigations. Now that their interaction has been observed, we may probe it further in experiments upon subject groups specifically selected for their high and low scores on each scale. In the present experiment the rarity of AP subjects prevented this; given, however, that the colour-tone effects also occur with Non-AP subjects, they may certainly be investigated in this way in the future: colour-tone interactions within groups thus selected should be similar, differing in direction between the groups. The use of such designs previously has revealed a number of complex relationships between groups, whereby, for example, the susceptibility of low-N introverts to nitrous oxide anaesthesia was significantly greater than that of low-N extraverts (Rodnight & Gooch,1963); and similar findings have been summarised by Claridge (1967).

The implications for intersensory integration work relate at this stage to a need for detailed examination of subjects in terms of their personality traits, motivation level and sensory acuity.

In the light of the intersensory findings reported above, perceptual researchers in general should closely observe the varying effects on performance of extraneous stimulation (of all modalities) that they might otherwise have thought irrelevant. Auditory workers in particular should realise the importance of controlling for the various levels of musicality. As a tool for eliciting certain individual differences in perceptual-motor tasks, the decision-time technique may in itself provide an objective index of the traits as yet measurable solely by questionnaire techniques such as the EPI. A current programme for research, launched by the writer on this basis, attempts to answer the following series of questions:-

(1) May the relative imagery strengths (auditory and/or visual) of individual subjects be discriminated by particular audio-visual decision-time effects?

(2) Do subjects identified on the basis of such effects as predominantly auditory or visual imagers derive significantly different benefits from educational material presented by various aural and visual techniques?

(3) Using the power of normal synaesthetic associations between the two modalities, can the efficacy of audio-visual techniques in education be improved to cater for individuals whose ability to extract and retain meaningful information depends on more personal forms of imagery?

Other questions broader still may follow: in attempts to isolate and identify the elements of psychological phenomena, and the inborn or acquired associations impinging upon them, the decision-time technique may prove a particularly useful method of quantification generally. The prior aim of those who use it might usefully be to consolidate the return from scientific ostracism of those imagery topics that so intrigued the early psychologists, and of which synaesthesia is a prime example. For, at this stage in its development, psychology may well prove ready to embrace such interests on a worthwhile theoretical footing.

5.4 A CRITERION FOR TONALITY.

The present work set out to probe a particular set of phenomena known to the musician but rather neglected in the psychological literature. From the study of synaesthesia it is but a small step to the problems of aesthetic response - preference for one colour before another, abnormal preferences and the stereotypic response to sensory stimuli - all relate to the ways in which stimuli are encoded and to the qualities with which they are equated. The influence of personality characteristics on such behaviour may surely be investigated in experimental situations of the type used here; while the suggested implications of the beat differential rationale for AP may clearly be tested by an attempt to induce AP in a non-possessor at a level fulfilling the demands of Bachem's criteria (immediacy of judgment, no conscious reference to other than the absolute cues, etc.). Of course, the beat differences arising from the theorised accumulation of error in intonation must be calculated empirically and a check made that the ear can indeed discriminate beats to this extent.

The proof of such a theory would have ready implications for the musicologist, for it would provide him with a new tonal quality with possible relevance to the ways in which musical styles have developed. The conventional analysis of tonality in music deals with the strictly relative effects produced by a key in its various juxtapositions with other keys: yet

> "Every sensitive musician has no doubt observed that in the works of (Mozart, Bach, Haydn and Beethoven) particular types of melody and figuration are associated with particular keys ..." (EINSTEIN,1944).

Further,

> "Beethoven was positive that keys had definite inner significance. 'He defended his position on logical grounds, claiming that each key is associated with certain moods, and that no piece of music should be transposed.'"
> (KANNE, quoted in SCOTT,1943).

Beethoven presents a particularly interesting subject for study in this respect, for whether his work was indeed influenced by absolute key characteristics and the aesthetic preferences that these may be supposed to elicit, is still a controversial issue. On the one hand it is hotly denied:

> "(In spite of) various attractive and fantastic utterances by Beethoven himself and by other composers ... the first thing that the reader needs to know about tonality is that the names of keys do not represent important aesthetic facts ...
>
> "The fact is that all notions about the character of keys in themselves are of the order of things which psychologists study as 'number-forms' and colour associations ... a psychological vagary about which no two persons need trouble to agree." (TOVEY,1944).

Musicologists acknowledge that Beethoven was 'adventurous' in his use of tonality, but cannot agree as to his '*criteria for tonality*';

and certain writers on the subject (Scott,1943; Newman,1963) have felt that too many features of his style remain incomprehensible if one does not accept that his individual (absolute) associations may have been influential.

This notion has recently been upheld by the observation of various consistent idiosyncracies in Beethoven's work by Preston (unpublished research,1969 to date: Sheffield Univ. Music Department). And a particularly interesting opportunity to explore the possible applications of the present theory in this respect is thus afforded. It seems that certain modulations (G to Eflat major, Aflat to C major, and others) occur regardless of the general tonality of the piece; and that certain moods, as expressed by for example the tempo and melodic features of the moment, may indeed be identified with these particular pairings. In answer to the writer's query as to the nature of music by Beethoven that may modulate from Aflat to C, Mrs. Preston instantly declared, "From darkness into sunlight!" (cf. in the 5th Symphony, 2nd movement). Certainly, in the context of the brightness curves isolated during the present work, Beethoven could not have chosen a more apposite key for the expression of darkness than Aflat (at the extreme peak of the darkness region). That Beethoven associated B with black does not agree with the present construction of B major as a bright key, but his evident reluctance to transpose his works into possibly more convenient keys than those in which they were written, supports the idea that particular key characteristics indeed served to underline for him the emotional connotations of music in general. Further examination of the contexts in which the individual keys are used by the many composers known to have been synaesthetic (CHAP.2), and an evaluation, for example, of brightness characteristics from one section of their works to the next, may indicate whether individual intersensory coding systems were operating when they wrote the works. Such influences are unlikely to trouble the composer - they may be his inspiration and guide; but to the musical analyst equipped with the rules of relative structure alone they can be a source of immense bewilderment.

In isolating the rules of a composer's absolute tonality sense, musicological detective-work of the sort that discovers that a particular composer's piano was tuned from its Middle C instead of the usual A, will certainly be relevant. Individual differences in these matters should be seen as our tools, not stumbling-blocks. Einstein (1944):

> "The question of the character of keys has (as yet) no generic answer. With each composer one must consider the character of <u>his</u> keys, and for this consideration not only psychology but history is necessary."

The application of scientific concepts to the study of the arts in this way may by some be considered as an intrusion on their mystery; others regard the subjective world of an artist as offering nothing in the development of scientific concepts. Yet music - and the Arts in general - is essentially the glorious expression of material gathered in a physically palpable way. As such we should refer to the features of the musician's mental landscape for clues to the physical mechanisms, just as we may study the latter in attempting to understand music itself.

"How hard, or rather impossible, is the attainment of certainty about questions such as these in the present life. And yet he would be a poor creature who did not test what is said about them to the uttermost, or abandoned the task before he had examined them from every side and could do no more"! (PLATO).

APPENDICES

APPENDIX I

QUESTIONNAIRES FOR STUDY OF MUSICALITY.

Several questionnaires were devised for use throughout this research for the collection of introspective data whenever a new and appropriate musical person was encountered. In addition to the tests reported in earlier chapters, each of the subjects in the two main experiments (C and D) completed the six Seashore Tests of Musical Talents (1939 Revision: Series A), and most of them the Eysenck Personality Inventory (1964) in both its forms (A and B).

The questionnaires that follow were actually presented on foolscap, though the transcript preserves their original proportions. They are:-

(1) A study of general musical sensitivity, with special emphasis on the aspects that may correlate highly in either direction with Pitch sense;

(2) A set of follow-up questions for claimants to Absolute Pitch;

(3) A response sheet for tonal synaesthetes.

(N.B. In APPENDIX 3, a fourth questionnaire - for ratings of 'key-brightness' - is discussed).

(1) Circulated to 100 musicians - responses by 80%.

University of Sheffield

Department of Psychology,
Mushroom Lane,
Sheffield 10.

I am conducting research into 'perfect pitch' and musical pitch sensitivity generally. As a basis for this work I need data concerning the various levels of musical talent, and I would be grateful if you - as a musician - would fill in this questionnaire, giving details wherever possible, and return it to me direct or at the above address; the information that you can provide will be most valuable.

The questions are designed to cover the main aspects of what is essentially an enormous field of inquiry; so if you feel that more remains to be said about your musical ability please do so (in the space provided and on extra paper if there is insufficient room here). Should you be in doubt as to any of the questions or feel that none of the suggested answers are appropriate please place a question-mark after your response. Thank-you in advance for your kind co-operation.

J.P.Baggaley; March, 1967.

....
Name of respondent (in full) Age

A) 1. At what age did you first take conscious part in any musical activity? (give details) ....
....

2. Do you consider yourself to be:
   i) Musical but below average? ...
   ii) Of average musical ability? ...
   iii) Musical above the average? ...
   iv) Exceptionally musical? ...

   Tick which response is appropriate

3. Have you a musical background? (give details of any musical ability shown by other members of your family).............
....
....
....
....
....

4. a) Are you, or do you plan to become, a professional musician or teacher of music? ....
b) If not, what? (does your work or intended work ever involve music indirectly, as broadcasting or Journalism, for example? ....
....

5. Is music your greatest interest? (If not, what interests you more?) ....

B) 6. Do you often go to concerts? ....

7. Do you buy records? ....

8. What type of music do you prefer? (rank in order of preference, from most to least preferable):

<u>E.g.</u> i) Baroque, classical, light-classical, romantic, jazz, modern-day popular, electronic, other types? .....
....
....

ii) Solo, chamber music, orchestral, other types?.....
....
....

9. Does the music of any particular composers, country or period interest you especially?(state reasons) ....
....
....
....
....
....

10. Are your musical tastes wide-ranging or highly specialised?
....
....
....

C) 11. a) Do you play, or have you ever played any musical instrument?
....
....

b) Do you sing, or have you ever sung? (solo or in a chorus?)
....
....

12. Have you ever received musical instruction of any sort? (if so, for how long? Do you still?).......................
....
....
....

13. Have you ever performed in public?.....................
....

14. a) Do you play with an orchestra or any other musical ensemble, or have you ever done so? ....

b) If so, of what sort(s)?...................................
....

With what regularity?...................................

How did you regard the experience? (fascinating, uplifting, too difficult, interesting or boring, etc.)............
....
....

15. a) Do you improvise or have you ever improvised musically?
....

b) On what instrument, if at all?...........................
....

c) Does improvising come easily to you?....................
....

16. Do you compose, or have you ever done so? (if so, for what combinations? How would you describe your style? Has any particular composer influenced you, and how?).............
....
....
....
....
....
....
....

17. Have you ever conducted, whether in public or for your own private entertainment?...................................
....

18. Have you ever directed others in any musical activity?.....
....
....

19. Have you ever been successful in a public music competition?
....
....

20. Do you regard yourself as a specific type of musician (pianist; baritone, composer, soprano, trumpeter, conductor, etc.) or are your musical talents more general?..................
....

D) 21. Do you readily recognise a musical composition again?......
....

22. Are you able to sing or play melodies or motifs correctly that you have heard several times (or even only once) before?...
....

23. a) Are you able to recognise and name the pitch intervals (octave, fourth, diminished seventh, major and minor third,etc.
....

b) Do you have any difficulty in playing or singing given intervals?..
....

24. a) After hearing an interval can you sing or play it in a transposed key?.......................................
b) Do you find practical transposition by sight (i.e. from sheet-music) at all difficult? ....
....
....

25. a) Do you associate particular colours, abstract qualities or other sensations with any of the following:- individual notes of the octave, keys, major or minor modes, pitch intervals, melodies, rhythm or style, particular musical works or instruments? (give details of any other association you may experience) ....
....
....
....
....
....
....
....
....
....
....

b) Have you any theory to account for this ability?........
....
....
....

26. a) Do you have a favourite note or key? (if so, state reasons)
....
....

b) Is there a particular note or key that you dislike? (if so, state reasons)..
....

27\. a) Does your musical ability have any particularly weak points? (*E.g.* rhythm or tempo discrimination, sensitivity to tone colour or pitch, etc.) ....

....

....

b) What are your stronger points? ....

....

....

28\. Can you identify given notes as belonging to a particular region of the musical compass, or is your sensitivity to pitch more accurate still? (how accurate is it?) ....

....

....

....

29\. Have you 'perfect pitch', or do you ever 'think' you have?

....

....

(IF YOU HAVE PERFECT PITCH, THERE ARE FURTHER QUESTIONS THAT I WOULD BE GRATEFUL TO ASK YOU IF YOU HAVE THE TIME - IN THE MEANTIME PERHAPS YOU WOULD ELABORATE ON THE NATURE AND EXTENT OF YOUR ABILITY IN THE EXTRA SPACE OVERLEAF)

30\. Do you have any musical ambition as yet unfulfilled, whether in creative or productive fields (composing or performing)?

....

....

....

....

E) 31. Do you have any other particular talent(s)?................

....

....

....

32\. Do you draw or paint easily from memory? (Do you have a photographic memory?) ....

....

....

33\. a) How good is your eyesight? (very poor, poor, average, good, very good?) ....

b) Have you a strong sense of smell? ....

(IF YOU HAVE ANY FURTHER COMMENTS TO MAKE PLEASE DO SO BELOW)

J.P.B.

(2) Circulated to 29 AP claimants - responses by all.

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Mushroom Lane,
SHEFFIELD, 10.

I am conducting research into musical pitch sensitivity, and in particular 'perfect pitch'. The following questions relate specifically to this phenomenon; they are designed as a basis to the problem only, and there will doubtless be more that you can say about the phenomenon from your own introspections - if so, please state any further information that you consider at all relevant, returning your answers to me direct or at the above address.

I wish to categorise the various types of perfect pitch, so please be as specific as possible and give as much detail as you like; for there may well be aspects of your own particular sensitivity to pitch that you alone can describe (connected attributes, for example). Should you be in any doubt as to any of the questions place a question-mark after your response. Thank-you in advance for your co-operation.

J. P. Baggaley: March, 1967.

A) 1. Does your perfect pitch cover the whole tonal range, or, for instance, the middle portion only; or is it perhaps limited exclusively to the standard pitch note 'a'?

2. Is your ability stabilised at a particular pitch standard (e.g. concert pitch), or does it fluctuate in one direction or another? Do other pitch standards confuse you?

3. Does your perfect sensitivity to pitch become at times less accurate (do you need to 'keep it in practice')?

4. Are you less accurate in discrimination of pitches of less familiar tone quality, or perhaps in discrimination of certain intervals?

5. Can you sing or play a specified note as well as identify a note heard?

B) 6. When were you first aware of the capacity? (Give details).

7. Do any of your relatives possess perfect pitch (or any other unusual ability)?

8. Do you consider that in your case the ability was inherited or developed due to external factors?

9. a) Do you feel that your musical abilities are primarily due to your possessing perfect pitch?
b) Is the capacity ever an impediment to aspects of musicianship, or perhaps an annoyance in any way?

C) 10. Do you know any others who claim to possess perfect pitch?

11. Do you consider that there may be various types of perfect pitch? (If so, state types - your knowledge of other individuals may help you here).

12. Do you have any theory to account for the phenomenon?

(Have you any FURTHER COMMENTS to make about 'perfect pitch' - e.g. have you any unusual ability, musical or otherwise, that you think may be connected with your possessing the capacity?).

J.P.B.

(3) Circulated to 29 AP claimants and 54 claimants
to chromaesthesia - responses by all.

UNIVERSITY OF SHEFFIELD

DEPARTMENT OF PSYCHOLOGY,
MUSHROOM LANE,
SHEFFIELD,
S10 2TN.

I am conducting research into musical sensitivity, and would be very grateful if you would fill in this sheet, and return it to me direct or at the above address.

The inquiry is in two sections:

1. I wish to know if there are individual musical notes or keys (whether major or minor) that you specifically like or dislike; please rank any preferences that you are aware of, in the left hand section of the following table, placing a figure 1 against your favourite note/ key, a 2 against the next in order of preference, and so on.

2. I would be interested to know if there are any particular colours, abstract qualities or other sensations that you associate with individual notes or keys; if so, please give your answer in the right hand section of the table below, specifying whether the association is prompted by the major or minor key, or by the note alone.

NAME: ....

1.	Preference ranking				
	Key		Note alone		
	Maj.	Min.		2. Associations (colour, etc.)	
D					D
G					G
A					A
C ♯ D ♭					C ♯ D ♭
E ♭ D ♯					E ♭ D ♯
F ♯ G ♭					F ♯ G ♭
A ♭ G ♯					A ♭ G ♯
C (B ♯)					C (B ♯)
B ♭ (A ♯)					B ♭ (A ♯)
E (F ♭)					E (F ♭)
F (E ♯)					F (E ♯)
B (C♭)					B (C♭)

(a) What is your reason for saying that you like a certain note or key BEST? ....

(b) What is your reason for saying that you like a certain note or key LEAST? ....

(If you would like to elaborate on any information you have given, please do so overleaf. Thank you in advance for your kind co-operation).

<u>J.P.BAGGALEY</u> (Oct.1968).

APPENDIX II

A CASE OF COLOUR-KEY SYNAESTHESIA.

"The confessions of a synesthete must sound tedious and pretentious to those who are protected from such leakings and drafts by more solid walls than mine are." (NABOKOV,1966).

An Appendix of the coloured hearing reports collected by this writer from each of his 54 synaesthetes would fill as many pages again. Much of their imagery is unique, and its content of the most infinite variety. Yet the range of individual experience in this field has been amply illustrated by previous investigators, and the following pages concentrate on a single case of chromaesthesia that demonstrates the remarkable power of synaesthetic imagery and the rare enthusiasm with which it is communicated. (The brackets will denote the editings and compression of several letters into a single sequence).

JKM (45 yrs. of age) is a musician and artist; he has AP and a MENSA score of 157. His mother, brother, grandmother and grandfather were all musical, and "at 18 months of age (he) achieved some local notoriety by singing ... many popular songs of the day in 'perfect tune'."

> "Some years later I began to sort out the intervallic rulings of Western harmony from the keyboard: I had no teacher in any usual sense: my mother directed me through a few (simple) pieces, but almost immediate boredom led me to try a thing like Liszt's 2nd Rhapsody. Suffice it to say it took me 2 weeks to get sense from its first page - after that I observed caution. So apart from a few tutor pieces I can claim to be self-taught.
>
> " ... Side by side with the music grew the sense of form in drawing - the colour sense seems always to have been there. From the age of 16 I practised drawing not at all, yet took it up at 40 to find the 'drawing and colour-capacity' but slightly lessened ... (T)he faculty whilst always excellent receives more excercise now than at any time in my life."

By a process that he regards as far deeper than a simple association of ideas, JKM considers each of the musical keys from a distinctly visual point of view; his own descriptions of these "cross-pollinations" are as follows:

"C major	Colourless (as water);	
C minor	A dull red (almost deep brick): matt;	
Dflat major	Blue-purple (velvet texture);	
Csharp minor	Red/Brown-Black (very dark);	
D major	Fairly light blue;	
D minor	Very pale light blue-white;	
Eflat major	Similar to C minor (slightly lighter): matt;	
Eflat minor	Infra-red/black (very dark);	
E major	Bright red (glossy);	
E minor	Very dull orange-red;	
F major	Ivory-yellow/white;	
F minor	Black-grey (between gloss and matt);	
(Fsharp major	Glossy black)	These two are counterparts but not the same;
Gflat major	Matt black)	
Fsharp minor	Very dark blue-black (glossy);	
G major	Yellow white/orange (pale);	
G minor	Grey black (almost as F minor, more glossy);	
Aflat major	Again black but towards grey;	
Gsharp minor	Black red (more glossy than Eflat minor);	
A major	Bright sunlit yellow;	
A minor	White-brown (pale);	
Bflat major	Dark blue;	
Bflat minor	Blue-purple (as Dflat major but darker velvet);	
B major	Dark blue (lighter than Bflat major);	
B minor	Blue with hint of green.	

"These colours are invariant regardless of the style or period of musical example."

In order to communicate his associations more satisfactorily, JKM undertook to prepare a set of colour illustrations; a photograph of the resulting 30x44 cm. parchment, on which each of the keys is depicted by a careful blend of oils, is presented with his permission as the frontispiece to this thesis - unfortunately a perfect reproduction of the hues was not possible. The colour-tone capacity dominates his artistic work completely, and he intuitively connects it with an accurate tonal recall:

"To quote an instance of how this subconscious colouring occurs: several weeks ago I retired to bed after playing amongst other things Schubert's Impromptu in Eflat. At around 4 a.m. I awoke with a chord running through my mind. Years of this sort of thing bade me get up to 'test' the chord on the piano. It was a perfectly pitched B minor, the exact inversion of the opening triad of the middle section of the Impromptu. I had been in a deep sleep from 1 a.m., but the chord, with its attendant colour, was still 'to the surface'.

"Another instance: whilst reading a book on Vermeer - my wife watching T.V. - a deep note on the set sounded the exact pitch of the Gsharp that opens Beethoven's A minor Quartet Op. 132. Here a tug-boat siren tallied with the exact pitch of a recording I have of this quartet. These examples with their colours I always re-check with either the piano or the recordings - though I do not need to. Always they are correct.

"This curious interchange works for me in reverse to a point, for I see the painting 'The Artist in his Studio' by Jan Vermeer as the visual music it is, a 4th Ballade of counterpoint in tonality, fugal painting, content, form, and vice versa ... Vermeer (was) a man with the most amazing colour sense: his tonal gradations are incredible. Like Chopin, he worked with split tonalities - my own terminology for certain 'between-pitch' states. May I elucidate: the opening notes of Chopin's Aflat Polonaise - Eflat octaves, both hands - form the dominant of Aflat. Then follows a chromatic 'climb' from the semitone below the dominant of the dominant or 'supertonic' - A-natural below Bflat. After the 3 chords that follow this 'climb', and the 5-beat reiteration of 4 notes that follows this ... we move to the split-tonality chord. For the next low chord is both the Eflat octave and E major in the right hand superimposed, suggesting a tonality of Aflat minor - but not so, for Chopin follows this with a climb chromatically from the dominant of the dominant namely Bflat ... So the chord has for we colour-conscious musicians a chameleonic effect. Rooted to Eflat we also experience E major ... we progress forward whilst rooted to the past Eflat colouration. This effect I have made the basis of my own string quartet in Eflat. Wagner used a similar idea in 'Rheingold', though more grandiose and not nearly so musicianly ... Ravel could be said to use a simplified version (of the effect) in the Dflat triad + A-natural that opens 'Ondine'. In the latter example the blue velvet of Dflat is 'sprinkled with yellow'.

"It is interesting to note the difference in subtlety between Vermeer's 'A Lady standing at the Virginals' and Gainsborough's 'Killmory'. The latter is quite monotone through its effects. Tonic and dominant harmony are here quite distinct, the colour-scheme as obvious as the chords of 'Auld Lang Syne'. But the Vermeer: what gradations of key-colour even are on the wall containing the pictures, in the satin gown and the play of shadow-colour - for all Vermeer's shadows are compounded of

> dark (hues). He has noticed that light takes on the colour of surrounding objects ... (T)he frame of the large picture has a Ravellian line of white light for its inner edge like the chord of 'Ondine' transposed from Dflat to Gflat ...".

> "(Of my own colours in oil: FRONTISPIECE) I have in each example set the colours slightly more vivid than I perceive them, this to correspond with a heightening of colours sometimes experienced during a long spell of applying oil paints to canvas: during this period of visual 'fatigue' a reverse takes place, and the colours intensify. In the juxtaposition of my 'darker' keys I have observed a relationship of 5ths, likewise of major to relative minor tonalities. An attempt to differentiate enharmonic equivalents was merely recorded in regard to the keys of Gflat major and Fsharp major: 'logically' it could be argued that no difference could exist, this division being imaginary, and some surprise may be registered at the difference between them (here) ... but the difference exists <u>only in regard to instruments of fixed tempering</u> - i.e. their tuning. The derivation (of a key) from the flattening or sharpening in the sequential cycle of fifths is in my experience a natural phenomenon, even though I am not a player of stringed instruments, etc., but of the keyboard. To illustrate my theory (of the split tonality sense) I might mention Chopin's use, in his Op. 53 (Aflat Polonaise), of the enharmonic double sharp key of Dsharp major; when modulation from E major was effected in the central episode the octaves drop in pitch a semitone, but Chopin obviously 'felt' the modulation to proceed upward ... to the leading note of E major (Dsharp). My theory (supposes) that a composer like Chopin with a strong sense of key-colour wrote with split tonalities subconsciously ... and the above is an interesting example for which theoretical proof exists, not only in his original manuscript, but also in the harmonization at the last semiquaver before the 'apparent' drop in pitch (mentioned above). The cycles of double sharp and double flat key signatures (in the section which follows the drop) have through scant usage tended to be ignored - a (necessary) consequence of our Western sense of definite pitch, for otherwise the phenomenon of 'absolute' pitch would have no meaning. As a further example of Chopin's split-tonality sense consider also the Etude 5 - Book 1 - in Gflat major: this has a quite different key derivation from say the Barcarolle in Fsharp major Op. 60. Beethoven too had this uncanny rightness of key: remember his avoidance of the key of B major! ... I would compare Beethoven with Vermeer in this respect. The latter's 'View of Delft' someone likened to a symphonic score: the description is apt. I think only a great musical mind can work with split tonalities as Vermeer does."

This selection of his ideas does little justice to the depth with which JKM has probed his synaesthesia, nor to the extent of its artistic application - in his 'audio-visual transformations' onto canvas and vice versa, and in his self-appointed research into the School of Delft. Difficulties arising from the conventional analysis of harmonic form in the mind of one sensitive to absolute tonal quality are carefully reconciled in the split-tonalities concept. It is evident that JKM's imagery directly underlies not only his aesthetic inspiration but his whole manner of thought and expression. And it is possible that without such 'leakings and drafts' the spirit of inquiry that his correspondence indicates might never have developed.

APPENDIX III

SUPPLEMENTARY QUESTIONNAIRE STUDY OF KEY-BRIGHTNESS.

The results reported above suggested that the main visual quality with which the tones interact is Brightness rather than, more specifically, Hue. It will be necessary to test this supposition empirically. By the design used in EXP/D, for example, we may observe the effects of a variable brightness pre-stimulus (visual) on the response times to tones; or we might require judgments of the visual stimuli given accompanying tonal stimulation as in EXP/C. Departing from our concentration on the single-tone stimulus, we should determine whether brightness qualities will also interact with tonality stimuli (the major and minor keys), and in a number of pilot sessions the writer has explored this possibility along the lines of EXP/C. Two subjects were asked to respond to the position (left or right) of patches of Black and White in a tachistoscope; they were given prior and simultaneous stimulation over headphones by scales and arpeggio sequences in the various keys. As AP possessors, both subjects are theoretically aware of certain key characteristics, though neither showed any sign of this by way of brightness-tonality interactions in the present task. Of course, the other experiments have shown that these effects are best observed across a group of subjects screened with respect to their personality traits; and in terms of the latter a zero interaction may be completely meaningful. Otherwise, two further possibilities should be considered:

(1) that the judgment task was too easy to be influenced in this way;

(2) that the subjects were by now too experienced in performing these tasks for the pre-stimulus to have any effect.

And in designing future experiments these considerations must be taken into account.

That the concept of 'key-brightness' can have definite meaning for the musician was shown by the following study. A questionnaire was prepared in which normal basic information about the subject was requested, also his ratings (on a semantic differential-type continuum from Bright to Dark) for each of the major and minor keys. The instructions were as follows:-

> "On the following two tables (overleaf) you are asked to rate each of the musical keys in terms of their 'brightness'. If you do not normally think of the keys in this way please try to make a good guess at the response you would make if you could! You may find it easier to think of the keys in other terms (e.g. soft/hard, warm/cold, rough/smooth, etc.) in which case try to translate such qualities into terms of bright/dark.
>
> "If a key is as 'bright' as any key could possibly be, place a tick in Column 1 on that line; if it is the 'darkest' key imaginable tick in Column 9 - otherwise use the intermediate positions in the line with 5 as exactly midway.
>
> "Of course, certain of the keys mentioned occur extremely rarely; if in such cases you are unable to make even a good guess at an appropriate rating, by all means leave that line blank. But please guess wherever possible. Thank you!"

Two copies of the rating matrix (below) were then presented, for separate assessments of the major and minor keys; introspections regarding the ease of the task were invited on its completion.

Subjects: The 29 AP claimants known to the writer each received by post a copy of the questionnaire, a covering letter and stamped-addressed envelope. At the time of writing, 18 of them have replied, each providing the basic information (for further analysis as the need arises), and all but three supplying key-brightness ratings also.

<u>Rating Matrix</u> (APP/III).

	BRIGHT								DARK	
Keys	1	2	3	4	5	6	7	8	9	
C♭										C♭
C										C
C♯										C♯
D♭										D♭
D										D
D♯										D♯
E♭										E♭
E										E
E♯										E♯
F♭										F♭
F										F
F♯										F♯
G♭										G♭
G										G
G♯										G♯
A♭										A♭
A										A
A♯										A♯
B♭										B♭
B										B
B♯										B♯

An opportunity for similar testing of a group of Non-AP subjects arose during a lecture by the writer on 'The Psychology of Music' to 31 members of the University Music Department; all provided the basic information, 28 of them the major-key ratings, and 26 the minor-key ratings.

<u>Results</u>: On the basis of the results reported earlier (FIGS.7 and 14), the ratings for the twelve principal enharmonics were ranged across the sequence of fifths; (as before, responses to the remaining enharmonics were less frequent). The fluctuations of brightness value across the fifths sequence (<u>TABLE 22</u>, <u>FIG.20</u>) follow the sinusoidal pattern reported in the main experiments, and thus provide, for both major and minor keys, further evidence of the important role of the brightness variable in the types of interaction we have considered.

TABLE 22.

Mean key-brightness ratings (APP/III).

	MAJ		MIN	
	AP	Non-AP	AP	Non-AP
C	6.73	6.79	3.80	4.38
G	6.87	7.21	5.20	4.96
D	7.00	7.64	5.20	4.81
A	7.73	7.39	6.00	6.27
E	7.27	7.14	6.00	6.31
B	6.87	6.46	6.13	5.35
Fsharp	6.53	6.54	5.27	5.31
Dflat	4.33	3.43	3.53	3.77
Aflat	4.53	3.93	4.07	3.73
Eflat	4.47	4.71	3.93	3.23
Bflat	5.60	4.89	4.53	3.54
F	5.60	5.61	4.07	4.27

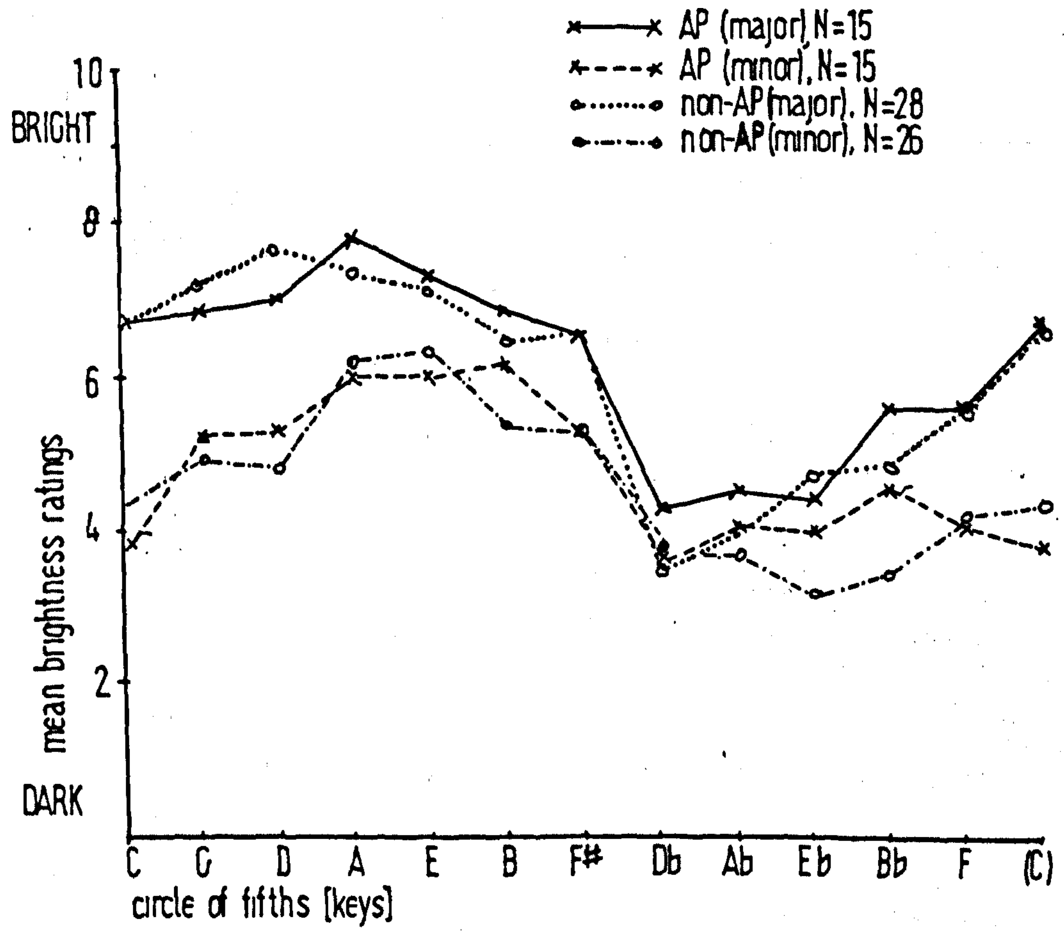

FIG. 20 Mean brightness ratings [APP. 3] of the principal major and minor keys by AP and non-AP claimants

For the purpose of the illustration, the values have been converted so that 9 = Bright, and 1 = Dark; the effect may thus readily be compared with that identified in the other study of tonality synaesthesia, i.e. EXP/B (FIGS.9). On submitting the data to two-way Analyses of Variance (TABLE 23), significant one-way differences are noted for each subject group on both factors (A) Major vs. Minor ($P_{AP} < 0.001$; $P_{Non-AP} < 0.0001$), and (B) the individual keys ($P < 0.0001$, both groups). Once again, a general logic is seen to underlie synaesthetic responses regardless of AP possession. If it were not for the results of EXP/D, we might assume the relationships due to a common knowledge of normal key usage in the repertoire.

TABLE 23.

Two-way analyses of variance between key-brightness ratings (APP/III) across (A) the Major and Minor modes, and (B) the 12 keys in each; analyses (1) AP claimants, and (2) Non-AP musicians.

		DF	S.S.	V.E.	F	P
(1)	Betw subjs	29				
	A	1	156.03	156.03	17.75	<0.001
	Subj w gps	28	246.06	8.79		
	Withn subj	330				
	B	11	336.50	30.59	12.56	<0.0001
	AB	11	39.01	3.55	1.46	(n.s.)
	B x Swg	308	750.08	2.44		
(2)	Betw subjs	53				
	A	1	281.42	281.42	49.65	<0.0001
	Subj w gps	52	294.76	5.67		
	Within subj	594				
	B	11	798.45	72.59	26.34	<0.0001
	AB	11	117.33	10.67	3.87	<0.0001
	B x Swg	572	1576.07	2.76		

As it is (CHAP.5), we suspect the agency of a more basic mechanism enabling tone-chroma recognition by musicians with no such prior knowledge; and, of course, we must test this hypothesis by experimental investigations of beat sensitivity and the equitonic tuning process. While encouraging future study of brightness association per se, the present results give welcome support for the possibility that rare AP-possessing musicians will not be the only subjects on whom the experiments may usefully be conducted.

PROGRAM ANALYSES IN ELLIOTT ALGOL.

(N.B. The spelling of 'program' is conventional)

The statistical analyses during this research were performed on the Department of Psychology's ELLIOTT 903 Computer. For the standard statistical procedures (analyses of variance, linear regression, etc.) a number of computer programs were already available, needing occasional modification only with regard to a chosen form of data input/output. In addition to the several dozen programs required of the writer as aids to his various sortings and examinations of massed data, the following programs were developed for:-

(1) 1st-harmonic analysis across the circular sequence of fifths: (EXPS/C and D);

(2) Kaiser's Varimax Rotation of orthogonal factor loadings (EXP/D).

The latter program, which contains various optional computations useful in factor analytic work, was later modified for the rotation of successive pairings of axes in N-dimensions (as in subsequent rotations mentioned during the Analysis of EXP/D). Both programs are in ELLIOTT Algol, and the writer owes many hours to the groundwork provided by Messrs. (1) Norman Marsh, and (2) Stuart Smith.

PROGRAM 1

1st-harmonic Analysis across the Circle of 5ths

Title HARMNY

Status Algol Program

Purpose Fourier analysis of the 1st harmonic component within scores ranged in circular sequence of fifths, and F-test significance check of the harmonic.

Method The null hypothesis is that scores ranged along the circle of fifths are random: a reduced spectral analysis is performed on the scores, identifying their mean, 1st harmonic, and residual components. Since a set of data is accurately reproduced by the sum of its harmonic components, its variance is equal to a pooling of the component variances. If the data are normally distributed - having no spectral structure - the variance of any component should be an estimate of the variance of the parent distribution. A ratio of any two variances obtained by partitioning in the usual way (Blackman & Tukey, 1959) should conform to the F distribution; and when the 1st harmonic of a set of scores is isolated its significance may be determined by the F-ratio between its variance and that of the residue. The present analysis is expedited by the equal division of points (consonance intervals) along the abscissa (circle of fifths).

Input On entry at 10 (ELLIOTT 903 computer), a set of 12 scores related to the circle of fifths; after computation, further such data is awaited and dealt with ad inf.

Output The corresponding set of 12 scores related to the data's 1st harmonic; amplitude and phase of the harmonic; F and P pertaining to its significance check.

```
HARMNY;

"COMMENT" REDUCED FOURIER ANALYSIS (TO FIRST HARMONIC)
  ACROSS TWELVE-NOTE SEQUENCES - WITH F-TEST;



"BEGIN" "INTEGER" J;
  "REAL" AMP1,PHASE1,VAR1,VAR0,SS,F,MEAN;
  "ARRAY" X[1:12]; "SWITCH" S:=NEXT;

"PROCEDURE" FURRY(SCORE,NUMBER,HARMONIC,AMP,PHASE,VAR);
  "VALUE" NUMBER,HARMONIC; "INTEGER" NUMBER,HARMONIC;
  "REAL" AMP,PHASE,VAR; "ARRAY" SCORE;
"COMMENT" ARRAY SCORE MUST HAVE MEAN EQUAL TO ZERO IN
  RANGE 1 TO NUMBER;
"BEGIN" "INTEGER" J; "ARRAY" SINVAL,COSVAL[1:NUMBER];
  "REAL" X,COSSUM,VARSUM,SINSUM;
  "IF" HARMONIC>((NUMBER-1) "DIV" 2) "OR" HARMONIC<1
  "THEN" "PRINT" PUNCH(3),DIGITS(3),''L'HARMONIC NO.',
  SAMELINE,HARMONIC,' NOT AVAILABLE',STOP;
  SINSUM:=COSSUM:=VARSUM:=0;
  "FOR" J:=1 "STEP" 1 "UNTIL" NUMBER "DO"
  "BEGIN" X:=6.2831853*HARMONIC*J/NUMBER;
    SINVAL[J]:=SIN(X);
    COSVAL[J]:=COS(X);
  "END" J;
  "FOR" J:=1 "STEP" 1 "UNTIL" NUMBER "DO"
  "BEGIN" SINSUM:=SINSUM+SCORE[J]*SINVAL[J];
    COSSUM:=COSSUM+SCORE[J]*COSVAL[J];
  "END" SUMS;
  SINSUM:=SINSUM*2/NUMBER;
  COSSUM:=COSSUM*2/NUMBER;
  AMP:=SQRT(SINSUM↑2+COSSUM↑2);
  PHASE:="IF" COSSUM "GE" 0 "THEN"
  ARCTAN(SINSUM/COSSUM)+0 "ELSE"
  ARCTAN(SINSUM/COSSUM)+3.14159265;
  "FOR" J:=1 "STEP" 1 "UNTIL" NUMBER "DO"
  VARSUM:=VARSUM+(SCORE[J]-SINSUM*
  SINVAL[J]-COSSUM*COSVAL[J])↑2;
  VAR:=VARSUM/(NUMBER-3);
"END" FURRY;

"REAL" "PROCEDURE" FRATIO(M,N,X); "VALUE" M,N,X;
  "INTEGER" M,N; "REAL" X;
"COMMENT" FISHER'S F-DISTRIBUTION WITH DF = M,N.
  COMPUTES PROB (F<X). BY CALLING FRATIO(1,N,T↑2)
  STUDENT'S T-DISTRIBUTION IS OBTAINED. SOURCE: COMM.
  A.C.M. ALGORITHM 322, E.DORRER,VOL.11,1968,P.116;
```

```
"BEGIN" "INTEGER" A,B,I,J; "REAL" W,Y,Z,D,P;
  A:=2*(M "DIV" 2)-M+2; B:=2*(N "DIV" 2)-N+2;
  W:=X*M/N; Z:=1/(1+W);
  "IF" A=1 "THEN"
  "BEGIN" "IF" B=1 "THEN"
    "BEGIN" P:=SQRT(W); Y:=0.31830989;
      D:=Y*Z/P; P:=2*Y*ARCTAN(P)
    "END" "ELSE"
    "BEGIN" P:=SQRT(W*Z); D:=0.5*P*Z/W
    "END"
  "END" "ELSE"
  "IF" B=1 "THEN"
  "BEGIN" P:=SQRT(Z); D:=0.5*Z*P; P:=1-P
  "END" "ELSE"
  "BEGIN" D:=Z*Z; P:=W*Z
  "END";
  Y:=2*W/Z;
  "FOR" J:=B+2 "STEP" 2 "UNTIL" N "DO"
  "BEGIN" D:=(1+A/(J-2))*D*Z;
    P:="IF" A=1 "THEN" P+D*Y/(J-1) "ELSE" (P+W)*Z
  "END" J;
  Y:=W*Z; Z:=2/Z; B:=N-2;
  "FOR" I:=A+2 "STEP" 2 "UNTIL" M "DO"
  "BEGIN" J:=I+B; D:=Y*D*J/(I-2); P:=P-Z*D/J
  "END" I;
  FRATIO:=P
 "END" FRATIO;

 NEXT: SAMELINE; VAR0:=MEAN:=0;
   "FOR" J:=1 "STEP" 1 "UNTIL" 12 "DO"
   "BEGIN" "READ" X[J];
     MEAN:=MEAN+X[J]; VAR0:=VAR0+(X[J]↑2)
   "END";
   MEAN:=MEAN/12; VAR0:=(VAR0-12*MEAN↑2)/11;
   "FOR" J:=1 "STEP" 1 "UNTIL" 12 "DO"
   X[J]:=X[J]-MEAN;
   FURRY(X,12,1,AMP1,PHASE1,VAR1);
   SS:=VAR0*11-VAR1*9;SS:=SS/2; F:=SS/VAR1;
   "PRINT" ''L'1ST HARMONIC'L'  AMPLITUDE =',AMP1,'
       PHASE =',PHASE1,'L'           F =',F;
   "IF" F>0 "THEN" "PRINT" ''L''S10'P =',ALIGNED(1,3),
   1-FRATIO(2,9,F); "PRINT"''L'';
   "FOR" J:=1 "STEP" 1 "UNTIL" 12 "DO"
   "BEGIN" "IF" J=7 "THEN" "PRINT" ''L'';
     "PRINT" ALIGNED(3,2),''S2'',
     MEAN+AMP1*COS((6.2831853*J/12)-PHASE1)
   "END"; "PRINT" ''L3'';
 "COMMENT" PHASES SHOULD BE IN RANGE -1.57 TO +4.71;

   "GOTO" NEXT

 "END";
```

PROGRAM 2

Varimax Rotation of Orthogonal Factor Loadings

Title OXYROT

Status Algol Program

Purpose Rotation of loadings on the orthogonal factor axes X and Y by Kaiser's Varimax method, with (optional) orthogonalisation of oblique data, Tucker's coefficient of congruence for estimation of agreement between factors, and root mean square solutions comparison.

Method A set of loadings/saturations/variables has been obtained on two main factors. In many cases the solution should probably, for better or worse, be allowed to remain as it is; in certain situations, however - e.g. if the factors are not easily identifiable, or if their inter-relationship causes effects to be confounded - a rotational method may be employed in order to clarify the meaning of the factors. By Kaiser's Varimax rotation attention is directed to the loadings on each factor with a view to establishing a rotational criterion at which the variance of the factor shall be a maximum (Horst, Chap. 18):

> "Since the elements are all positive by hypothesis, the maximum for each vector would be achieved if all of its elements were either large or 0. Therefore, in working towards the maximization of the variance criterion one tends to reduce the intermediate loadings to a minimum and to maximize the number of large and small loadings."

The method assumes that the factors are unrelated, their axes orthogonal; and the questions arise as to how far any two sets of factor loadings may be correlated before their relationship has a confounding effect on the rotation analysis. The present program bypasses this problem by use of the Gram-Schmidt process for orthogonalisation of a matrix by the following transformation (Harman, p. 239):

$$a_X = b_X + b_Y r;$$

$$a_Y = b_Y \sqrt{1 - R^2}$$

where a_X and a_Y are the new (orthogonalised) loadings on factors X and Y after the transformation of the old (oblique) loadings, and b_X and b_Y, with reference to their correlation (R). If the OXYROT user wishes to employ the orthogonalisation option the data should first have been presented to a correlation program. For succession of events in computation of the final (rotated) solution see the commentary on the Algol printout.

<u>Input</u> On entry at 10 the following parameters:

(V) Number of variables (there will be V loadings on each factor); V may not exceed 139;

(Z) Required output mode; (if Z=0 the solution may be obtained either on the teleprinter or punch in the normal way; but if output is Auto and Z=1 the solution is output to the teleprinter with a selected output of the loadings alone (raw and rotated) to the punch; if Z=2 or Z=3 see <u>Additional Options</u> section below);

(R) Correlation coefficient (if R=0, the two factors are assumed orthogonal else rendered orthogonal by the degree of obliquity previously indicated by a correlation program). Assume orthogonality (with R=0) where possible.

(Data) $X_1 \ldots\ldots\ldots\ldots X_V$) loadings are likely to be
) correlation coefficients (real),
positive and negative.
$Y_1 \ldots\ldots\ldots\ldots Y_V$)

Output Raw (input) loadings with root mean square for each factor; Varimax criterion, latent root, root mean square, and loadings pertaining to the rotation of factors at 5, 2, and 1 degrees of tolerance, where 1 degree provides the most precise estimate (see Algol printout).

(Additional Options)- Coefficient of Congruence (Tucker, p.43; Harman, p.269) ranging from +1 for perfect agreement between factors (or -1 for perfect inverse agreement) to zero for no agreement:

$$\mathrm{Phi}_{XY} = \frac{\Sigma(a_X \cdot a_Y)}{\sqrt{\Sigma a_X{}^2 \cdot \Sigma a_Y{}^2}}$$

where Phi is the coefficient of congruence between factors X and Y obtained by division of the sum of corresponding loading products by the square root of the product of the sums of squared loadings. On reset and jump to 10, input the number of variables on a factor, instruction numeral 2, and the loadings $X_1 .. X_V, Y_1 .. Y_V$. (This is not a correlation coefficient, as Harman, p.270 explains).

- Root mean square index of similarity between two complete solutions from same data (e.g. solution from input parameter R=0 compared with that where R "ne" 0 and denotes a degree of obliquity to be orthogonalised by Gram-Schmidt transformation). The formula - which bears distinct resemblance to another popular measure - is discussed by Harman (pp. 269, 312):

$$(A - B)_{RMS} = \sqrt{\frac{\sum(X_A - X_B)^2}{MN}}$$

where $(A - B)_{RMS}$ is the index of agreement between A and B solutions yielded by the root of the mean (MN = number of factors times number of loadings on each) of the sum of squared differences between corresponding loadings in the two solutions. On reset and jump to 10, input the number of variables in each solution (MN), instruction numeral 3, and the loadings $X_1 \ldots X_{MN}$. $Y_1 \ldots Y_{MN}$.
(A simple-minded index denoting perfect agreement by zero, both this and the coefficient of congruence may generally be used to the same end, but see Harman, pp. 268-272).

Validation of Program - The computation of coefficient of congruence was checked against Harman's results (p. 270) for loadings matrices A and B on p. 252, and agrees to the point of two rounding errors at the third decimal place;
- the RMS solutions comparison yields results in complete agreement with those of Harman (p.312) from data on p. 311.
- for the case of Varimax rotation where data assumed orthogonal complete agreement is obtained between OXYROT and Harman's final solution (p. 309) from initial solution on p. 302; also with Harman's solution (p. 310) from initial solution (first two principal components) on p. 137;
- for the case of a Varimax rotation of axes originally correlated though rendered orthogonal by the Gram-Schmidt

transformation formulae, OXYROT solutions were compared with the following Harman solutions:

(1) Harman's 3 Direct Oblimin solutions (p. 336) from 2-factor loadings (p. 205); OXYROT agreement with 1st and 2nd Harman solutions:- $(X-Y)_{RMS} < 0.23$; Coefficient of Congruence >0.93 (<u>N.B</u>. Harman's 3rd solution agrees with neither of his other two beyond 0.71 congruence).

(2) Harman's Direct Oblimin primary pattern solution (Table 15.12, p. 340) from initial solution (first two principal components) on p. 137; OXYROT agreement:- $(X-Y)_{RMS} = 0.64$; Coefficient of Congruence = 0.91 (<u>N.B</u>. a number of Harman solutions themselves show less agreement than they yield with corresponding OXYROT solutions, and Harman's suggestion of the Gram-Schmidt process employed by OXYROT "as a stepping-stone to the rotational problem" (p. 239) is concluded worthy).

<u>Warning</u> Before rotating, check initial hypotheses in the light of Harman (1967), and Horst (1965) to ensure that the Varimax paradigm and Gram-Schmidt process are justified.

```
OXYROT;

"COMMENT" PERFORMS KAISER-STYLE VARIMAX ROTATION OF THE LOADINGS/
  SATURATIONS/VARIABLES (V) ON ORTHOGONAL FACTORS X AND Y - ALSO
  ROOT MEAN SQUARE COMPUTATION FOR EACH SET OF LOADINGS OBTAINED,
  OPTIONAL ORTHOGONALISATION OF OBLIQUE AXES AS PER HARMAN,P.240,
  COEFFICIENT OF CONGRUENCE BETWEEN SETS OF LOADINGS AND (X-Y)RMS
  SOLUTIONS COMPARISON (HARMAN,PP.268-272), AND CHOICE OF OUTPUT;


"BEGIN" "REAL" A,B,G,E,NUMER,DENOM,ANGLE,V0,V1,R,R1,PI;
  "INTEGER" K,J,V,D,Z; "SWITCH" S:=START,L1,L2,TEST,CONG;
  SAMELINE; PUNCH(3); DIGITS(1); ALIGNED(2,3);
  "READ" V,Z;
"BEGIN" "ARRAY" SAT,ROTSAT[1:V,1:2],H,PARU,PARV[1:V],
  L,S2,S4[1:2],T[1:2,1:2];

"PROCEDURE" OUT(ZZ,Q,Q1); "VALUE" ZZ,Q,Q1;
  "INTEGER" ZZ,Q; "REAL" Q1;
"BEGIN" "IF" ZZ=0 "THEN" PUNCH(3) "ELSE" PUNCH(1);
  "IF" Q=0 "THEN" "PRINT" ''L`` "ELSE"
  "IF" Q=1 "THEN" "PRINT" ''L`X'L`` "ELSE"
  "IF" Q=2 "THEN" "PRINT" ''L`Y'L`` "ELSE"
  "IF" Q=3 "THEN" "PRINT" ''S2``,Q1 "ELSE"
  "IF" Q=4 "THEN" "PRINT" ''R40`` "ELSE"
  "IF" Q=5 "THEN" "PRINT" ''L` 'S40`` "ELSE"
  "IF" Q=6 "THEN" "PRINT" ''S7`` "ELSE"
  "IF" Q=7 "THEN" "PRINT" ALIGNED(6,3),Q1 "ELSE"
  "PRINT" Q1; PUNCH(3)
"END" OUT;

"PROCEDURE" LINES(K); "INTEGER" K;
"BEGIN" "INTEGER" COUNT,GOAL;
  GOAL:="IF" Z=0 "THEN" 7 "ELSE"
  "IF" Z=1 "THEN" 12 "ELSE" 0;
  "IF" K=1 "THEN" COUNT:=1;
  "IF" COUNT=GOAL "THEN"
  "BEGIN" OUT(0,0,0); "IF" Z=1 "THEN"
    OUT(Z,0,0); COUNT:=1
  "END" "ELSE" COUNT:=COUNT+1
"END" LINES;
```

```
START: "IF" Z>1 "THEN" "GOTO" CONG;
  "PRINT" ''L'LINEAR CORRELATION = '; "READ" R;
  "PRINT" ''L'RAW LOADINGS'S45'RMS'; PI:=3.141592;
  "FOR" J:=1,2 "DO"
  "BEGIN" OUT(0,J,0); L[J]:=0;
    "IF" Z=1 "THEN" OUT(Z,0,0);
    "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
    "BEGIN" "READ" SAT[K,J]; LINES(K); OUT(0,3,SAT[K,J]);
      "IF" Z=1 "THEN"
      "BEGIN" LINES(K); OUT(Z,3,SAT[K,J])
      "END";
      L[J]:=L[J]+SAT[K,J]↑2
    "END"; "FOR" K:=5,6,6 "DO" OUT(0,K,0);
    OUT(0,8,SQRT(L[J]/V))
  "END";

"COMMENT" SUCCESSIVE ACCURACIES LOOP HERE;
  "FOR" D:=5,2,1 "DO"
  "BEGIN" R1:=R/SQRT(L[1]*L[2]);
    "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
    "BEGIN" H[K]:=0;
      "FOR" J:=1,2 "DO" H[K]:=H[K]+SAT[K,J]↑2;
      H[K]:=SQRT(H[K]);
      "FOR" J:=1,2 "DO" SAT[K,J]:=SAT[K,J]/H[K]
    "END" NORMALISATION;
    "FOR" J:=1,2 "DO"
    "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
    "BEGIN" SAT[K,1]:=SAT[K,1]+SAT[K,2]*R1;
      SAT[K,2]:=SAT[K,2]*SQRT(1-R1↑2)
    "END" ORTHOGONALISATION;
    V0:=0; OUT(0,0,0); "IF" Z=1 "THEN" OUT(Z,0,0);

TEST: V1:=0;
  "FOR" J:=1,2 "DO"
  "BEGIN" S2[J]:=S4[J]:=0;
    "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
    "BEGIN" S2[J]:=S2[J]+SAT[K,J]↑2;
      S4[J]:=S4[J]+SAT[K,J]↑4
    "END";
    V1:=V1+V*S4[J]-S2[J]↑2
  "END";
  "IF" ABS(V1-V0)<0.01 "THEN" "GOTO" L2;
  V0:=V1;
```

```
"COMMENT" NOW TAKE THE TWO FACTORS AND CALCULATE
  PARAMETERS FOR ANGLE OF ROTATION;
  A:=B:=E:=G:=0;
  "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "BEGIN" PARU[K]:=SAT[K,1]↑2-SAT[K,2]↑2;
    PARV[K]:=SAT[K,1]*SAT[K,2]*2;
    A:=A+PARU[K];
    B:=B+PARV[K];
    G:=G+(PARU[K]↑2-PARV[K]↑2);
    E:=E+PARU[K]*PARV[K]*2
  "END";
  NUMER:=E-2*A*B/V; DENOM:=G-(A↑2-B↑2)/V;
  "IF" DENOM=0 "THEN"
  "BEGIN" ANGLE:=PI/2; "GOTO" L1
  "END";
  ANGLE:=ABS(NUMER/DENOM);
  ANGLE:=ARCTAN(ANGLE);
  "IF" NUMER "GE" 0 "AND" DENOM>0 "THEN" "GOTO" L1;
  "IF" NUMER "GE" 0 "AND" DENOM<0 "THEN"
  "BEGIN" ANGLE:=ANGLE+PI/2; "GOTO" L1
  "END";
  "IF" NUMER<0 "AND" DENOM<0 "THEN"
  "BEGIN" ANGLE:=-(ANGLE+PI/2); "GOTO" L1
  "END";
  "IF" NUMER<0 "AND" DENOM>0 "THEN" ANGLE:=-ANGLE;
L1: ANGLE:=ANGLE/4;
"COMMENT"IF THE ANGLE OF ROTATION IS LESS THAN THE SUCCESSIVE
  ACCURACIES (5,2,1 DEGREES) THE ROTATION IS IGNORED;
  "IF" ABS(ANGLE)<PI*D/180 "THEN" "GOTO" TEST;
"COMMENT" NOW FORM THE TRANSFORMATION MATRIX AND USE IT FOR
  ROTATING THE TWO FACTORS;
  T[1,1]:=T[2,2]:=COS(ANGLE);
  T[2,1]:=SIN(ANGLE);
  T[1,2]:=-T[2,1];
  "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "FOR" J:=1,2 "DO" ROTSAT[K,J]:=0;
  "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "BEGIN" ROTSAT[K,1]:=SAT[K,1]*T[1,1]+SAT[K,2]*T[2,1];
    ROTSAT[K,2]:=SAT[K,1]*T[1,2]+SAT[K,2]*T[2,2]
  "END";
"COMMENT" THE FACTOR SATURATIONS ARE RESTORED AND VARIANCES
  CALCULATED;
  "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "BEGIN" SAT[K,2]:=ROTSAT[K,2]; SAT[K,1]:=ROTSAT[K,1]
  "END";
```

```
L2: "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "FOR" J:=1,2 "DO" SAT[K,J]:=SAT[K,J]*H[K];
  "PRINT" ‘‘L2’’,D,‘ DEGREE PRECISION
VARIMAX CRITERION = ’,ALIGNED(6,4),V1,
‘‘L’ROTATED LOADINGS’; "IF" D=5 "THEN" "PRINT"
  ‘‘S27’LATENT ROOT’;
  "IF" Z=1 "THEN" OUT(Z,4,0);
  "FOR" J:=1,2 "DO"
  "BEGIN" OUT(0,J,0); "IF" Z=1 "THEN" OUT(Z,0,0);
  S2[J]:=0;
    "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
    "BEGIN" LINES(K); OUT(0,8,SAT[K,J]); "IF" Z=1 "THEN"
      "BEGIN" LINES(K); OUT(Z,8,SAT[K,J])
      "END"; S2[J]:=S2[J]+SAT[K,J]↑2
    "END"; OUT(0,5,0); OUT(0,7,S2[J]); "PRINT" ‘‘S3’’;
    OUT(0,8,SQRT(S2[J]/V))
  "END";
  OUT(0,0,0); "IF" Z=1 "THEN" OUT(Z,4,0);
  "FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
  "BEGIN" SAT[K,2]:=SAT[K,2]/SQRT(1-R1↑2);
    SAT[K,1]:=SAT[K,1]-SAT[K,2]*R1
  "END"

"END" OF SUCCESSIVE ANGLES OF ROTATION;

"FOR" J:=1 "STEP" 1 "UNTIL" 6 "DO"
"BEGIN" OUT(0,0,0); "IF" Z=1 "THEN" OUT(Z,0,0)
"END";
"GOTO" START

"END";

CONG: "BEGIN" "REAL" C,XX,YY; "ARRAY" X,Y[1:V];
"COMMENT" COEFFICIENT OF CONGRUENCE AND (X-Y)RMS FOR
  NEWLY INPUT DATA;
C:=XX:=YY:=0;
"FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
"BEGIN" "READ" X[K]; XX:=XX+X[K]↑2
"END";
"FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
"BEGIN" "READ" Y[K]; YY:=YY+Y[K]↑2
"END";
"FOR" K:=1 "STEP" 1 "UNTIL" V "DO"
C:="IF" Z=2 "THEN" C+X[K]*Y[K] "ELSE" C+((X[K]-Y[K])↑2);
"IF" Z=2 "THEN" "PRINT" ‘‘L’COEFF CONG =’,C/SQRT(XX*YY)
"ELSE" "PRINT" ‘‘L’(X-Y)RMS =’,SQRT(C/V)
"END"

"END";
```

APPENDIX V

PHOTOGRAPHS OF EXPERIMENTAL APPARATUS.

Photograph (a)

Photograph (b)

Photograph (a) shows the main features of the 'flexible experimental system' earlier depicted in FIGURE 10. At top left, a tape recorder sound source with optional volume control provided by the attenuator on its right. The audio-signal switch (top right) fragments a continuous output, as from the oscillator beneath the switch, for presentation to the subject. The output may be monitored by the experimenter via his headphones seen on the desk, and the pulsing of output checked on the oscilloscope (bottom left). The sequence of audio and visual presentation, also the record of response times and error, is controlled by the RDP behaviour apparatus underneath the tape-recorder and by the auxiliary relay block in the foreground. In photograph (b) the mode of visual and auditory stimulus presentation to subjects in EXP/C is shown (tachistoscope and headphones: subject on left, experimenter on right). (...)

Photograph (c)

Photograph (d)

EXP/D was controlled in the same manner - photograph (c) - though the visual stimuli were projected onto the wall. Photograph (d) shows the projection apparatus and juxtaposition of experimenter (foreground) and subject (behind the partition). As with the frontispiece, a totally accurate reproduction of the colour stimuli in these photographs was not possible; more precise specifications of both apparatus and stimuli are given in the introductions to the appropriate experiments. (...)

Photograph (e)

Photograph (f)

Apart from the projector, the only light source during EXP/D was the lamp at the experimenter's console - see photograph (e). While responses were made to the stimuli presentation on headphones, the subject's arms were rested easily on the table - photograph (f). The pool of light at the left-hand of the screen in this last photograph results from the unfortunate introduction of an arc-light during the photographic session: colour displays during the actual experimental sessions were uninterrupted as in photographs (c) and (e).

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