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A STUDY OF THE RELATIONSHIP OF SINGING ACCURACY TO THE PITCH-MATCHING ABILITIES OF EIGHTY-ONE SUBJECTS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

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degree of

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BY

IRA C. POWELL

Norman, Oklahoma

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A STUDY OF THE RELATIONSHIP OF SINGING ACCURACY TO THE PITCH-MATCHING ABILITIES OF EIGHTY-ONE SUBJECTS

APPROVED BY

Robert H. Keith

Gail de Stwolinski

Jimmy F. Harp

Margaret S. Haynes

C. Russell Mathis

DISSERTATION COMMITTEE

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CHAPTER I

PURPOSE AND SCOPE OF STUDY

Relevancy

The human voice is unique among musical instruments. Although it requires no external accouterments, the voice is capable of expression throughout an extended range of pitches and degrees of intensity. While the pitch of a tone produced by a keyboard instrument is determined by the key or keys depressed, the human voice has no such pitch regulation system. Nor can it be likened to other instruments requiring digital, labial, or pedal dexterity or combinations thereof. With all its flexibility and capability to produce tones with seemingly infinite pitch gradations, the human voice is frequently heard singing badly out-of-tune. Music educators, and particularly choral directors, are continually imploring singers to make pitch adjustments of tones which tend to prevail just a bit above or below true pitch.

The inability of some children to sing with acceptable pitch accuracy is a source of frustration for school music teachers. Should the child with the out-of-tune voice, whose singing often resembles sustained speech patterns with incorrect inflections, be encouraged to channel his attention and interest to some other activity? Should he thus be deprived of the experience of participation in group singing or school music programs? What effect might such exclusion from vocal music activities have on the child? Or should he be included in the vocal music classes and programs, although his musical contribution to the ensemble sound might be negative rather than positive?

Although it is not the purpose of this study to answer these questions which confront the school music teacher, it is the relevancy of these and many other similar questions to the credo of music education which has prompted this investigation. The writer became interested in the possibility that some children cannot be expected to sing acceptably in tune because of a disparity in pitch sensitivity of his two ears. Such a possibility is suggested by Seashore.

> It is generally stated in the textbooks that frequently the two ears seem to be tuned to a different pitch; for example, so that a tone of, say, 435 d. v. in one ear may sound of the same pitch as a tone of the pitch of 430 d. v. in the other ear. This matter has not yet been treated adequately by experiment. It presents an important field for further investigation because it would seem reasonable to suppose that if the pitch-differentiating mechanism in one ear is entirely independent of that in the other, there might be physical conditions which could develop a permanent difference

> in the two ears and develop acute changes which would cause temporary differences in the registering of pitch.
>
> . . . Theoretically, it would seem probable that there should be very large differences in the power of discrimination of the two ears, and since we do not ordinarily isolate one ear from the other, either in hearing music or in ordinary experiments in the hearing of tones, such differences might pass undetected. Careful study of that problem might, however, throw important light on the pitch-differentiating mechanism in the ear.[1]

If, indeed, it were possible to determine the existence of a disparity in the tuning of a person's two ears, and the extent thereof, it might also be possible to predict the likelihood of his ability to sing with acceptable pitch accuracy. Thus the question arises concerning the existence of a definite relationship between a person's singing accuracy and his pitch-matching abilities. Expanded, the question becomes one of the extent of the disparity of pitch perception beyond which there is little likelihood of satisfactory vocal competence. The use of the qualifying terms "acceptable" and "satisfactory" is intentional, albeit the writer may be vulnerable to criticism because of the absence of an established standard of acceptability.

The primary objective of this study was to determine the extent of the relationship, if any, between pitch-matching ability and the ability to sing familiar tunes with acceptable accuracy of intonation. Such an investigation would necessarily require a sizeable sample. Testing

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[1] Carl E. Seashore, _The Psychology of Musical Talent_ (Boston: Silver, Burdett and Co., 1919), p. 75.

equipment and procedures were devised to acquire the necessary data from which relationships, correlations and conclusions might be drawn.

Auditory Anomalies Considered

A study such as this which involves certain aspects of the physics of sound and acoustics, and touches on the complexities of otology and audiology, must have carefully drawn boundaries of inquiry. However, the vast literature on these subjects contains information germane to this study and essential in dealing with the problems presented by the testing procedures.

In the pitch-matching portion of the tests given to the eighty-one subjects, explained in detail in a subsequent chapter, it was anticipated that some of the subjects might be sufficiently knowledgeable to listen for the beats produced by two tones of almost identical sound wave frequencies. Bartholomew presents a profoundly simple explanation of this acoustical curiosity.

> A special case of the principle of interference occurs when two tones sound at the same time but at slightly different frequencies, the resulting pulsations of tone being called beats. This may be understood by imagining two persons clapping hands, one at the rate of three claps a second, the other at the rate of four. Their claps will coincide once a second, and when they do they will sound doubly loud. Beats result from the alternate coinciding and interfering of two wave trains, for when a pulse of compression coincides with another pulse of compression, and rarefaction with rafefaction, the sound is strengthened; but when a pulse of compression

coincides with one of rarefaction the sound is weakened.[2]

Helmholtz was the first to make a definite study of the phenomenon of beats and to resolve the problem to scientific analysis and explanation. In his monumental work, Sensations of Tone, he refers to this "interference," as he calls it, and gives a physician's insight of the ears' sensitivities to dissonance.[3]

The use of earphones by the test subjects for introduction of test tones to be matched was not only required for purposes of tone separation, but as a precaution against possible distortions of the tones from hearing via bone conduction. Littler mentions that a certain amount of sound energy reaches the cochlea directly through its bony structure and surround, although not an important contribution to normal hearing.[4]

Bartholomew gives a description of the effects of bone conduction in terms readily understood by the layman as he mentions specific problems encountered by singers and instrumentalists.

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[2] Wilmer T. Bartholomew, Acoustics of Music (New York: Prentice-Hall, Inc., 1942), p. 58.

[3] Hermann L. F. Helmholtz, M.D., On the Sensations of Tone as a Physiological Basis for the Theory of Music, trans. Alexander J. Ellis (3d ed.; London: Longmans, Green, and Co., 1895), pp. 159-73.

[4] T. S. Littler, Director, Wernher Research Unit on Deafness, King's College Hospital Medical School, London, The Physics of the Ear, Vol. III of International Series of Monographs on Physics, ed. G. H. A. Cole (New York: The Macmillan Co., 1965), p. 219.

> Apparently the passage of sound directly to the cochlea through the skull in 'bone conduction' introduces certain distortions. Thus, in an individual possessed of normal hearing, a vibrating tuning fork heard through the skull bone by clamping the teeth on its base, will sometimes appear slightly higher in pitch than when heard normally. Also, violinists (whose tones may be heard either through the ear canal, membrane, and middle ear in the usual way, or by transmission directly to the cochlea through the chin rest of the instrument and the bones of the chin and head), sometimes complain of the difficulty of discriminating pitch, whereas when listening to another player they have no such difficulty. Is this difficulty due perhaps to bone conduction? A similar thing occurs also with singers, who often can hear very fine pitch errors in others and yet be unaware of making similar or greater ones themselves.[5]

The electronic equipment used in the pitch-matching portion of the testing was equipped with independent volume or intensity controls, one for the fixed frequency pitch and another for the variable frequency pitch. This was done as a precaution against another possible distortion of the pitches being matched. Bartholomew explains this type of distortion and the resultant necessity of independent volume controls, as well as verbal instructions to the test subjects to use no higher volume than necessary to hear each of the tones distinctly.

> A type of distortion is produced in the middle ear. The nature of the bones of the middle ear is such that when any pure tone louder than a moderately soft intensity is produced, the action of these bones is such as to introduce the octave and higher harmonics as well. The louder the tone, the greater is this type of distortion, and the more prominent become the higher harmonics. The effect lessens as the pitch rises. In the case of a very loud tone of low or medium pitch, even

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[5] Bartholomew, p. 218.

> though it may be produced physically by sound waves of pure simple harmonic motion, the psychological experience resulting from its physiological reception in the cochlea is equivalent to that of a fundamental plus a long series of overtones. If it be complex to start with, it is made even more complex in the ear.[6]

A related problem to the one just mentioned is discussed by Littler, stating that a pure tone with a constant frequency of vibration will seem to change in pitch as the intensity is varied. He acknowledges this as a concern of musical conductors and vocalists in tuning various instruments of the orchestra to a tuning fork, and the tuning of voices to certain instruments.[7]

As previously stated the primary objective of this study was to see if a relationship might be established between singing accuracy and pitch-matching ability. The pitch-matching tests presented some of the subjects with challenges far more difficult for them than the writer had anticipated. Intervals of fifths, sixths, sevenths, octaves, ninths, tenths, and sometimes still larger, were selected as matching pitches or unisons by several test subjects. This disparity in pitch perception is called diplacusis and is described by Littler.

> In some diseases of the ear a false sense of pitch is produced. It can be demonstrated by presenting tones in turn to the two ears and asking the listener to adjust their frequencies until they appear of equal pitch. If the difference in frequencies is more than a normal difference limen for frequency, the abnormality can be referred to as <u>diplacusis</u>. Diplacusis

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[6] Ibid. [7] Littler, p. 123.

> is experienced to a slight extent by some normal subjects and is usually present in cases of perceptive deafness, particularly in the instances of deafness due to Ménière's disease. It is believed to be due to physical deformity in the cochlea; in Ménière's disease there is evidence that the endolymphatic capsule becomes distorted and in other perceptive deafnesses there is definite damage to parts of the hair cell system of the cochlea or the Organ of Corti.[8]

The difference limen mentioned by Littler is "the minimal increment in a stimulus needed to produce a just-noticeable difference in sensation."[9]

Culpepper, whose research included the testing of children for hearing acuity, diplacusis, tonal memory and pitch difference discrimination, defines diplacusis as "an anomalous characteristic of hearing in which a fixed tone is heard at two different pitches in the separate ears. Diplacusis was found to be subject to minor changes from day to day both as to the amount and the direction of deviation above or below the fixed tone."[10]

Preliminary research of literature available on various related aspects of this study revealed that considerable work has been done in the area of binaural hearing. In contrast with normal hearing where both ears simultaneously hear a sound from a single source, binaural hearing

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[8] Littler, pp. 258-59.

[9] S. S. Stevens and H. Davis, Hearing (New York: John Wiley & Sons, Inc., 1938), p. 451.

[10] Leon Raines Culpepper, "A Study of the Hearing Impairment in Defective Singers" (unpublished Ed.D. dissertation, Dept. of Music, George Peabody College for Teachers, 1961), p. 120.

is the complete isolation of separate sources of sound with each ear receiving only the sound intended for it. Succinctly defined, "the term binaural beat (BB) refers to a class of perceptions produced by pure tones when one tone stimulates only one ear and the other tone, of a slightly different frequency, stimulates only the other ear."[11]

An opposing viewpoint is frequently encountered in scientific writings. Often presented with comparable clarity and supported by equally impressive investigative and experimental procedures, evidence is introduced which is apparently diametrically contradictory to previous findings. The following is an example of such dichotomy, taken from an article in a trade magazine of the electronics industry, and written by a research engineer for Radio Corporation of America, Charles J. Hirsch.

> Two notes of different frequency do not produce beats or roughness when heard separately by the two ears, although they do produce beats or roughness when both notes are heard by one ear.
>
> . . . .
>
> When C and C# are combined in one ear, they produce an annoying rough grinding sound, similar to that made by a badly overloaded audio-frequency amplifier. The grinding sound disappears when the tones are heard by separate ears simultaneously. Instead, one hears the two tones individually or, sometimes, a compromise tone.[12]

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[11] Jacques Rutschmann and Leo Rubinstein, "Binaural Beats and Binaural Amplitude-Modulated Tones: Successive Comparison of Loudness Fluctuations," The Journal of the Acoustical Society of America, XXXVIII, No. 5 (1965), p. 759.

[12] Charles J. Hirsch, "Some Aspects of Binaural Sound," Spectrum, Vol. IV, No. 2 (1967), p. 82.

Although no attempt here is made to reconcile these divergent viewpoints, the testimony of this writer is that the beats were distinctly heard on numerous occasions while working with the testing equipment for this study. The auditory sensation can best be described as eerie or wierd.

The compromise tone, as mentioned by Hirsch, is also noted by other writers, including Littler, as "combinational tones." However, Littler is careful to prescribe increases in intensities of both tones of the order of sixty decibels (db.) sound pressure level before such combinational tones appear.[13]

Studies of the effects of masking have been made in which it has been determined that a tone heard distinctly by one ear can be effectively nullified or masked into obscurity by another tone of identical pitch heard by the other ear at a substantially increased intensity or volume level.[14] The likelihood that this might prove confusing to the test subjects for this study was discounted, provided they were cautioned to maintain equal volume levels of the test tones, to the subjects' best judgements, and that such levels were no greater than necessary to hear both tones distinctly.

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[13] Littler, p. 131.

[14] Georg von Békésy, Experiments in Hearing, trans. and ed. E. G. Wever (New York: McGraw-Hill Book Co., Inc., 1960), p. 265.

This brief summary has merely brought to the attention of the reader some of the problems which might be contributory to an individual's pitch-matching difficulties. Research literature in the areas of acoustics, audiology, and psychology abound with references to these complexities, and medical research has diagnosed several otological conditions which tend to compound these difficulties. Thus, this study of the relationships between singing accuracy and pitch-matching abilities is pregnant with pedagogical implications.

CHAPTER II

TESTING AND SCORING PROCEDURES

General Information Regarding Sample

The eighty-one subjects in this study encompassed an age range from nine to sixty years, with 21.1 years as the mean age. Some degree of selectivity was exercised in the recruitment of test subjects in that an effort was made to obtain test data on as many subjects as possible having difficulty singing "in tune" or matching pitches of tones.

Thirty-one subjects could be classified as having singing and/or tone-matching difficulties. This group represented thirty-eight per cent of the sample. The other fifty subjects tested could be classified as having more than a casual interest in music, although not necessarily performers nor music majors.

Musical experience, both instrumental and vocal, was ascertained of each individual and these factors evaluated and statistically weighted to have an appropriate bearing on the findings. The musical experience and background reported by the subjects ranged from virtually none to that of the highly trained professional music teacher.

Singing Accuracy Tests and Scoring

A test for singing accuracy was given each subject. Six tunes were chosen from the literature of hymns, patriotic songs, folk songs, and spirituals. Criteria for the selection of the six test tunes were familiarity of melody and lyrics, absence of awkward or difficult melodic intervals, and reasonably limited range. The six songs used were: "Come, Thou Almighty King;" "America;" "Swing Low, Sweet Chariot;" "Holy, Holy, Holy;" "Battle Hymn of the Republic;" and "Way Down Upon the Swanee River."

Each melody was written out in two different keys, along with the lyrics, to accommodate any voice range likely to be encountered, and supplied to the subject. A tape recording was made of each melody, in both keys, played on a newly-tuned piano, for use as the sole accompaniment to the singing. Spoken instructions for the singer preceded each melody on the tape indicating the pitch and tempo.

The subject selected two tunes for his test melodies from the six available. A somewhat relaxed and informal atmosphere was maintained as the subject completed the information questionnaire and selected his test tunes. This was done to assure as much freedom from self-consciousness and timidity as possible. It was made clear that his singing was to be done in complete privacy and was simply an integral part of this research project, not a vocal audition for soloists nor for a choral group.

The tape-recorded accompaniment was heard by the subjects first in the right ear via professional quality earphones as the selections were sung. Utilizing a separate two-channel stereo tape recorder, the singing of the subject was recorded on one channel while the piano accompaniment to his singing was recorded on the other channel. After the subject had sung both songs, the earphones were reversed and the procedure repeated, this time with the accompaniment being heard in his left ear. Then the singing was repeated again with the accompaniment being heard in both ears simultaneously. The separate-track recording of the accompaniment and the singing made possible the isolation of one from the other for purposes of critical examination.

Two evaluative procedures were applied to the singing tests. First, a tone-by-tone analysis was made of the singing of each subject. Each incident of faulty intonation was recorded. The tape-recorded singing of each subject was carefully heard by the writer, often replaying individual melodic intervals, phrases, and motives several times. Each tone sung with inaccurate intonation, in the judgment of the writer, was counted. An accuracy percentage score (the number of intonation errors committed divided by the number of opportunities for error) was then computed for each subject in each of the three categories: accompaniment heard by right ear, accompaniment heard by left ear, accompaniment heard by both ears simultaneously.

Second, four members of the Voice Faculty from University of Missouri - Columbia were asked to evaluate the over-all accuracy of intonation of the singing of the subjects. An ordinal scale rating, ranging from zero through ten, was given by each evaluator on each of the two songs sung by the subject in each of the three categories aforementioned. These ratings by the evaluators were totaled, averaged, and transformed into percentages of accuracy for each category of each subject's singing. These singing accuracy scores were averaged with the accuracy percentage scores of the tone-by-tone analysis to obtain a final score for singing accuracy for each subject in each of the three categories.

A monophonic tape recorder, Realistic Model 7A7ss, with a frequency response of 50 to 10,000 cycles at 7-1/2 inches per second tape speed, was utilized to provide the pre-recorded accompaniment, via earphones, to the subject's singing.

The headset used was a Clark Model 100 stereophonic, with a frequency range of 10 to 20,000 cycles and a frequency response of plus/minus 3 db., 20 to 10,000 cycles.

The stereophonic tape recorder used to record the accompaniment on one channel and the subject's singing on the other channel was a Realistic Model 909, having a frequency response from 50 to 12,000 cycles at 7-1/2 inches per second tape speed.

Pitch-matching Tests and Scoring

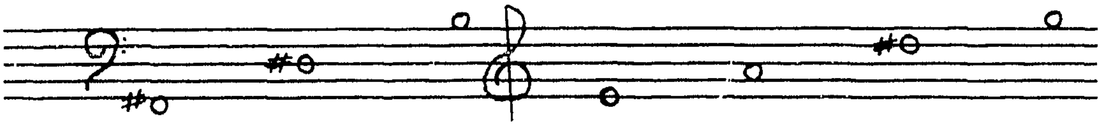
Fixed-frequency oscillators were used to generate individual sine wave tones for matching purposes. The sine wave signal was chosen to present the least complex tone for the subject to match. Seven frequencies were selected to present pitches for matching that were within the normal range of the human voice. They were first presented singly to the left ear to be matched by a second tone heard by the right ear. The tone heard by the right ear was also a sine wave tone, generated by a variable-frequency oscillator. The pitch of the latter was determined by the subject by careful manipulation of a dial knob until the two tones were identical, at least to his satisfaction. The Clark Model 100 stereophonic headset, previously described, was employed in this testing procedure.

The seven test tones were presented in the order of ascending pitch. Illustration 1 presents the pitches and the actual frequencies, in cycles per second, of the seven test tones used.

A beat frequency counter, coupled with a one-second interval timer, was used to determine the difference in cycles per second between the fixed-frequency tone and the tone from the variable-frequency oscillator selected by the subject as a matching pitch. A visible image of the difference between the two tones was produced by an oscilloscope. This image was used to determine the direction of error, either above or below zero difference, between the tones after the subject had matched them to his satisfaction. Neither of these two instruments of measurement was visible to the subject during the test to aid him in the selection of matching pitches.

ILLUSTRATION 1

PITCHES OF TEST TONES



Tone	1	2	3	4	5	6	7
Freq.	92.5	155.5	247.0	329.6	440.0	622.2	784.0

As each test tone was matched by the subject, the error, if any, was recorded in numerals representing actual cycles per second. Thus, if the fixed-pitch tone in the left ear was matched by a tone in the right ear that was, for example, four cycles per second higher in pitch as indicated by the counter and the oscilloscope, the subject's score for that pitch, right ear, was "plus four." Had the match been four cycles per second lower than the fixed-pitch tone, the score would have been "minus four."

After each of the fixed-frequency tones had been heard in the left ear, and a matching pitch selected for the tone heard by the right ear, the same sequence of test tones was repeated with the fixed-frequency tone being heard by the right ear and the matching pitch to be selected being heard by the left ear. The tone-matching ability of the subject was thus tested a total of fourteen times, with seven scores being recorded for each ear.

The stereophonic headset previously described, through which the two tones were heard, provided absolute separation of the two tones as regards air conduction of sound. Effects of hearing by bone conduction were minimized with the inclusion of separate volume controls for each ear and by verbal instructions to keep the volume as nearly equal as possible and no louder than necessary to hear both tones distinctly.

The possibility of a disparity in hearing acuity of the subject's ears was another reason for the inclusion of separate volume controls, although it was not within the scope of this study to consider the effects such disparity might have on pitch recognition and matching.

The electronic equipment used to conduct the pitch-matching tests was constructed by James D. Warren, Chief Research Engineer, Dorsett Industries, Norman, Oklahoma, according to requirements furnished by this writer. Illustration 2 presents a schematic diagram of the electronic equipment used in the pitch-matching tests.

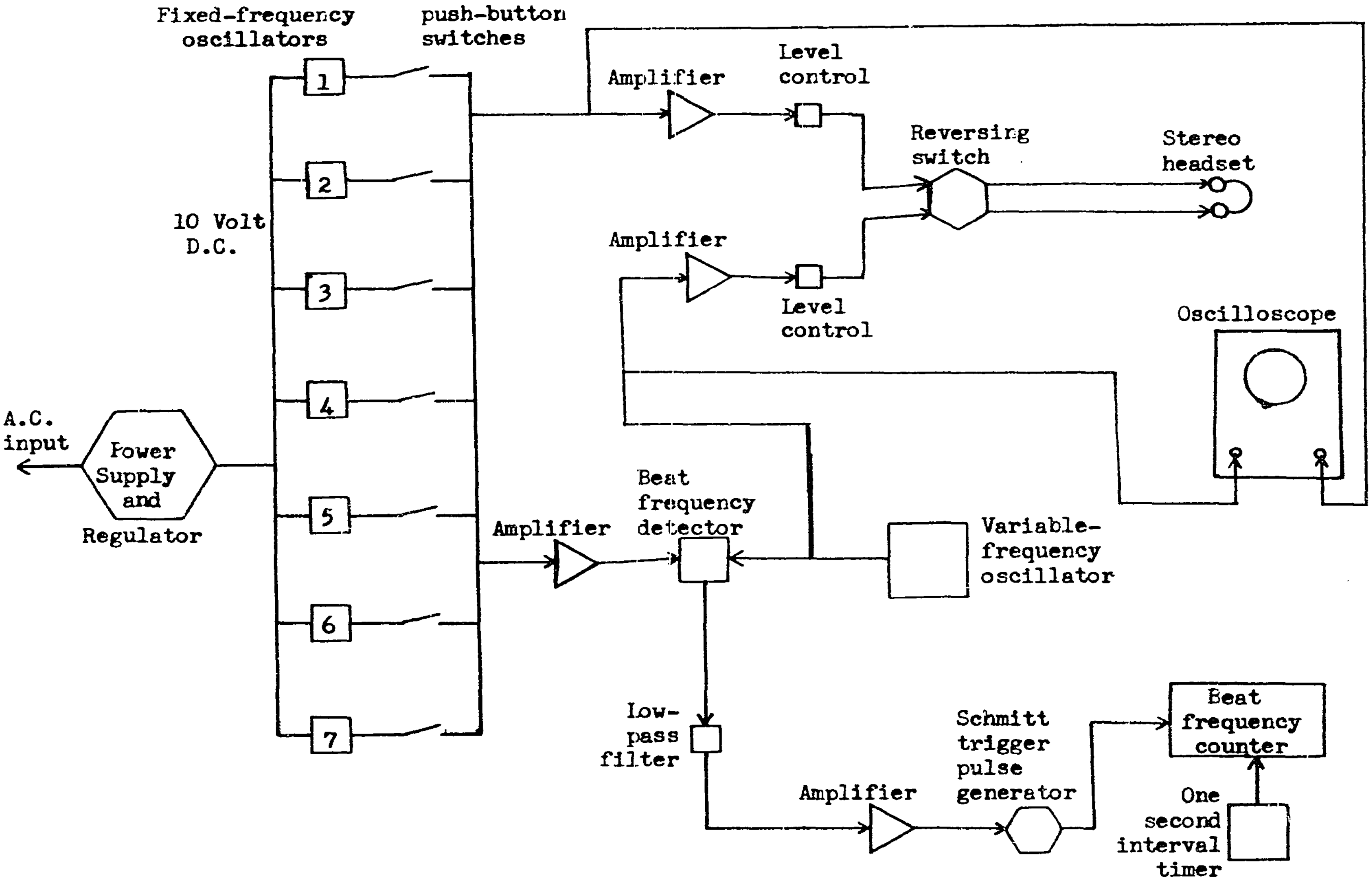


ILLUSTRATION 2: SCHEMATIC DIAGRAM OF TONE-MATCHING EQUIPMENT

CHAPTER III

ANALYSIS OF DATA

An IBM 7040 Digital Computer was employed for the several statistical analyses of the data. The computer card for each of the eighty-one subjects included such personal information as: age, sex, known hearing impairment or deficiency, right-handedness or left-handedness, and whether or not eyeglasses or contact lenses were worn. Data from which computerized analyses were to be made included: direction and extent of error, measured in cycles per second, for each of the seven pitch-matching test frequencies, right ear; direction and extent of error, measured in cycles per second, for each of the seven pitch-matching test frequencies, left ear; singing accuracy score, accompaniment heard by right ear; singing accuracy score, accompaniment heard by left ear; singing accuracy score, accompaniment heard by both ears simultaneously; vocal music experience factor; and instrumental music experience factor.

The vocal and instrumental music factors were calculated from the information supplied by each subject at the time of his testing. The vocal experience factor was determined by doubling the years of private vocal study reported, to which was added the years of choral experience in organized church and/or school choral groups. The instrumental experience factor reflects the years of instrumental study and includes the total years of band and/or orchestral experience.

The statistical weighting of the private vocal study element in the vocal experience factor was recommended by the consulting statisticians since the private vocal study, intuitively, was to be so significant. The statistical procedures applied to the raw data required that the formula for determining the vocal experience factor be uniformly applied for each of the eighty-one subjects. Similarly the formula for determining the instrumental experience factor was to be uniformly applied for each subject, but the application of identical procedures for calculating these two factors was not a requisite.

The utilization of computerized facilities for the various statistical analyses of the data required that a standardized terminology be applied to particular elements of datum. A knowledge of this terminology will facilitate the reading and understanding of the tables of statistical data to be encountered. A brief glossary of terms applicable to this study is presented for the convenience of the reader.

GLOSSARY OF TERMS AND SIGNS APPLICABLE TO THIS STUDY

Variable 1, singing accuracy.

Variable 2, pitch-matching.

Variable 3, instrumental music experience.

Variable 4, vocal music experience.

Problem Right, computations involving singing accuracy scores, accompaniment heard only by right ear; and pitch-matching scores, total frequency deviation errors on seven test signals, variable frequency signal heard by right ear.

Problem Left, computations involving singing accuracy scores, accompaniment heard only by left ear; and pitch-matching scores, total frequency deviation errors on seven test signals, variable frequency signal heard by left ear.

Problem Both, computations involving singing accuracy scores, accompaniment heard by both ears simultaneously; and pitch-matching scores, total frequency deviation errors on fourteen test signals, seven variable frequency signals heard by each ear.

* (asterisk), appears with certain statistical results involving Variable 2. Inverse scoring procedures used to obtain raw data of Variable 2 is occasionally reflected in negative (-) numerical results in certain computations of statistical relationships. Instances in which the minus sign may be disregarded

without affecting the validity of the results are indicated by the asterisk. Higher pitch-matching scores of raw data indicated inferior pitch-matching abilities. All other scores reflected relative degrees of superiority in ascending increments.

The product-moment coefficients of correlation of the means of the four variables were computed. The correlation between singing accuracy and vocal music experience was unexpectedly high, even higher in two of the three instances, than the correlation (not unpredicted) between singing accuracy and pitch-matching ability. Another interesting relationship revealed by the statistical analysis is the comparatively low correlation between pitch-matching ability and instrumental music experience. Table 1 presents the product-moment correlation coefficients of the means of the four variables.

TABLE 1

CORRELATION COEFFICIENTS OF MEANS

Variables	Problem Both	Problem Right	Problem Left
2 - 1	-0.583347*	-0.533311*	-0.619329*
3 - 1	0.511639	0.485457	0.504634
3 - 2	-0.342119*	-0.312109*	-0.317192*
4 - 1	0.610006	0.582027	0.607763
4 - 2	-0.428682*	-0.391128*	-0.397396*
4 - 3	0.555889	0.555889	0.555889

A simultaneous correlation and regression analysis was applied to the raw data. The program was of a generalized nature designed to handle any parametric correlation and regression analysis problem.[15] A regression analysis made possible an estimate of the value of the independent variable from given values of the dependent variable. In this case the procedure became a multiple regression analysis, since the dependent variable was singing accuracy and the independent variables considered were pitch-matching, instrumental experience, and vocal experience.

> It often is the case that, when two or more independent variables are considered jointly, the estimating procedure is far more accurate than when only one independent variable is used. The coefficient of multiple correlation . . . measure[s] the closeness of the relationship between the dependent variable and the joint simultaneous configuration of the independent variables.[16]

The multiple correlation coefficient was computed to be 0.724, indicating a statistically significant correlation between the subjects' singing accuracy scores (dependent variable) and the combined effects of pitch-matching abilities, instrumental experience, and vocal experience (independent variables). This coefficient may be interpreted roughly as: 72.4% of the variation in singing accuracy

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[15] Computer Programs for Statistical Analysis, Computer Research Center Statistical Group, University of Missouri, 1967, (manual for users of Computer Research Center facilities), Section 2.1 - 2.35. (Mimeographed.)

[16] Samuel B. Richmond, Statistical Analysis (New York: The Ronald Press Company, 1964), p. 446.

scores is the result of the combined influences of the independent variables.

The regression coefficients of the independent variables in this study are interpreted as the average change in the dependent variable associated with a unit change in the appropriate independent variable. In this computation the dependent variable is Variable 1, singing accuracy, with constant factor of 63.045. Table 2 indicates the regression coefficients of the independent variables.

TABLE 2

REGRESSION COEFFICIENTS OF INDEPENDENT VARIABLES

Ind. Var.	Reg. Coef.
2	-0.308*
3	0.522
4	1.292

Interpreting the significance of the regression coefficient of independent variable, Variable 4 (vocal experience), a unit change in either direction of this factor should result in a change of more than one unit (1.292) in the dependent variable, Variable 1 (singing accuracy).

Although it was not the intent of this study to measure the influence of every possible factor which might conceivably affect singing accuracy, even if such were not an outright impossibility, the influences of pitch-matching ability, instrumental experience, and vocal experience are demonstrably statistically significant as previously expressed by the multiple correlation computation of 0.724. Another test of significance of these influences, as revealed in the regression analysis, can be found in the analysis of covariance of these variables. The F Value was computed at 28.319 for 3 and 77 degrees of freedom, considerably greater than 2.72 which is the level of statistical significance at the 5% level for 3 and 80 degrees of freedom (nearest point of comparison).[17] Because of the inverse scoring procedures applied to the raw data, and because of the particular characteristics of the computer program applied to these analyses, the F Value indicates significance.

T Values were computed as a test of the validity of the means of the independent variables. Table 3 presents these computed values.

TABLE 3

T VALUES OF THE INDEPENDENT VARIABLES

Ind. Var.	T Val.
Var. 2	-4.208*
Var. 3	2.034
Var. 4	3.461

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[17] Richmond, p. 580, citing George W. Snedecor, Statistical Methods (5th ed.; Ames Iowa: The Iowa State University Press, 1956).

"Student's" Distribution at the .05 level of significance for 60 degrees of freedom (nearest point of comparison) is 2.000.[18] Here, again, significance is indicated, contrary to the usual application of the T Value as a test of validity of means, because of the characteristics of the computer analysis program and the inverse scoring procedures applied to the raw data.

A partial correlation analysis of singing accuracy and pitch-matching scores was computed, with instrumental and vocal experience factors held constant. The resultant correlation coefficient was 0.583, which is interpreted as 58.3% of the variations in singing accuracy scores being generally accounted for by the influence of pitch-matching ability, devoid of the influences of instrumental and vocal experience factors.

Still another statistical treatment applied to the data was a stepwise regression procedure, a routine which uses the Tableau Method of Effroymson.[19] Beginning with the two variables having the highest correlation, the influence of each of the other two variables is incorporated

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[18] Daniel S. Lordahl, Modern Statistics for Behavioral Sciences (New York: The Ronald Press Company, 1967), p. 339, citing R. A. Fisher and F. Yates, Statistical Tables for Biological, Agricultural, and Medical Research (Edinburgh: Oliver & Boyd, Ltd.), Table III.

[19] Computer Programs for Statistical Analysis, Section 2.36, citing N. R. Draper and H. Smith, Applied Regression Analysis (New York: John Wiley & Sons, Inc., 1966), pp. 171-72.

by successive steps. By this cumulative process the following facts of interest were obtained:

> (1) 37.2% of the variations in singing accuracy scores can be generally accounted for by the influence of vocal experience;
>
> (2) 49.9% of the variations in singing accuracy scores can be generally accounted for by the influences of vocal experience and pitch-matching scores, considered simultaneously;
>
> (3) 52.4% of the variations in singing accuracy scores can be generally accounted for by the influences of vocal experience, pitch-matching, and instrumental experience scores, considered simultaneously.

The foregoing statistical analyses and the accompanying interpretations were applied to raw data within the framework previously defined in the glossary as Problem Both. Similar analyses were also made of data for Problem Right and of data for Problem Left. Although the mathematical results of these analyses differed slightly, as might be anticipated, the results of the analyses of Problem Right and the results of the analyses of Problem Left closely paralleled those of Problem Both.

For purposes of comparison Table 4 presents a statistical summary of all the evaluative and analytical procedures applied to the data from this study.

The reader will undoubtedly notice the sequential deviation of the independent and the dependent variables in the first two steps of the stepwise regression analysis, Problem Left, shown in Table 4. It has been previously mentioned that the procedural approach in this type of analysis is to begin with the two variables having the highest correlation coefficient. In the case of Problem Left the highest correlation was between pitch-matching ability and singing accuracy, thus the explanation for the change in sequence of the variables.

TABLE 4

STATISTICAL SUMMARY

Item	Problem Both	Problem Right	Problem Left
Product-Moment Correlations of Means			
	Mean	Mean	Mean
Variable 1	71.593	66.269	67.852
Variable 2	178.839	94.481	84.358
Variable 3	9.098	9.098	9.098
Variable 4	7.209	7.209	7.209
	Std. Dev.	Std. Dev.	Std. Dev.
Var 1	26.376	25.946	26.517
Var 2	315.573	176.340	166.858
Var 3	9.798	9.798	9.798
Var 4	7.013	7.013	7.013
	Corr. Coef.	Corr. Coef.	Corr. Coef.
Vars 2 - 1	-0.583347 *	-0.533311 *	-0.619329 *
Vars 3 - 1	0.511639	0.485457	0.504634
Vars 3 - 2	-0.342119 *	-0.312109 *	-0.317192 *
Vars 4 - 1	0.610006	0.582027	0.607763
Vars 4 - 2	-0.428682 *	-0.391128 *	-0.397396 *
Vars 4 - 3	0.555889	0.555889	0.555889
Simultaneous Correlation and Regression Analysis with Four Variables Considered			
	Dep Var 1	Dep Var 1	Dep Var 1
Constant	63.045	57.276	59.936
Mult R	0.724	0.687	0.749
F Value	28.319	23.040	32.845

TABLE 4--Continued

Item	Problem Both	Problem Right	Problem Left
	Reg. Coef.	Reg. Coef.	Reg. Coef.
Ind Var 2	-0.308 *	-0.500 *	-0.679 *
Ind Var 3	0.522	0.497	0.491
Ind Var 4	1.292	1.275	1.272
	T Value	T Value	T Value
Ind Var 2	-4.208 *	-3.752 *	-5.160 *
Ind Var 3	2.034	1.872	1.985
Ind Var 4	3.461	3.329	3.559

Partial Correlation Analysis--Variables 3 and 4
Held Constant

	Dep Var 1	Dep Var 1	Dep Var 1
Constant	80.312	73.683	76.155
Mult R	0.583	0.533	0.619
F Value	40.750	31.400	49.157
	Ind Var 2	Ind Var 2	Ind Var 2
Reg. Coef.	-0.487 *	-0.784 *	-0.984 *
T Value	6.383	5.603	7.011

Stepwise Regression Analysis--Cumulative Procedures

	Step 1	Step 1	Step 1
	Ind Var 4	Ind Var 4	Ind Var 2
	Dep Var 1	Dep Var 1	Dep Var 1
	Mult R 0.372	Mult R 0.338	Mult R 0.383
	Step 2	Step 2	Step 2
	Ind Var 2	Ind Var 2	Ind Var 4
	Dep Var 1	Dep Var 1	Dep Var 1
	Mult R 0.499	Mult R 0.449	Mult R 0.538
	Step 3	Step 3	Step 3
	Ind Var 3	Ind Var 3	Ind Var 3
	Dep Var 1	Dep Var 1	Dep Var 1
	Mult R 0.524	Mult R 0.473	Mult R 0.561

The possibility that a "learning factor" might have existed during the testing procedures, particularly the pitch-matching tests, required the data to be subjected to a test for determination if this, indeed, had occurred. A computer program, "Duncan's New Multiple-Range Test," was selected to be applied to the data.[20] Analysis of the results indicated no statistically significant learning factor existed, as indicated by the means of the pitch-matching scores of right ear tests compared with means of the pitch-matching scores of left ear tests. Some evidence does exist that a slight learning factor, or experience value, may have occurred during the testing of either the right ear or the left ear of certain subjects, but even this could be considered statistically negligible.

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[20] Computer Programs for Statistical Analysis, Section 1.18 - 1.20.

CHAPTER IV

OBSERVATIONS, CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Observations

Data from individual test subjects revealed that thirty-one persons had total deviation scores on the pitch-matching tests of 78 or higher. Only five of these subjects received singing accuracy ratings of 70% or higher. These five persons reported totals of thirty-five years vocal music experience and thirty-five years instrumental music experience, which might account for their acceptable singing performances despite less than sensational pitch-matching abilities.

Thirty test subjects received singing accuracy ratings of 66% or lower, of whom only four had total deviation scores on the pitch-matching tests of 65 or lower. These four subjects reported totals of five years vocal music experience and twenty-six years instrumental music experience, which again might account for their acceptable pitch-matching abilities despite relatively unsatisfactory singing accuracy scores.

Remembering the inverse scoring procedures applied to these two tests, one might conclude that singing accuracy scores were higher as total deviation scores on the pitch-matching tests were lower. The data confirms this to be true. Restated another way, test subjects scoring poorly on pitch-matching ability also received correspondingly poor ratings on singing accuracy tests. To this extent was an initial hypothesis of this study borne out, which was that the pitch-matching ability of an individual could provide a valid index to his ability to sing with acceptable accuracy of intonation.

Through the process of statistical analysis of scores from both tests, weighted with the experience factors of vocal and instrumental music experience, the only defensible conclusion, however, which can be drawn in this regard is that at best pitch-matching ability can serve only as an index of probability of satisfactory singing accuracy. This would seem to further underscore the importance of both vocal and instrumental music experiences in the development of a consciousness of pitch and intonation in singing.

As expected, some abnormality appeared in a few scores. Occasionally a test subject would mismatch a pitch to an exorbitant degree, perhaps explainable by an imbalance of volume of the two tones being heard. This might result in his hearing a predominance of the octave or a combinational tone. An examination of the data from these tests indicates that such occurrences were rare, particularly when the total number of individual pitches matched is considered. The reader will recall that each of the eighty-one subjects completed fourteen pitch-matching tests.

Illustrative of the occasional abnormality in the scoring patterns was the test subject (No. 32) who had a commendable singing accuracy score of 81, but whose pitch-matching score was, comparatively speaking, not too much better than that of another subject (No. 20) whose singing accuracy score was zero, indicating that not a single tone of the test songs was sung "in tune."

Another example of such inconsistency is the case of two test subjects (No. 2 and No. 27) having similar pitch-matching scores of 10 and 11, but who achieved singing accuracy scores of 88 and 63 respectively, a decided incongruity.

Only one test subject (No. 80) possessed perfect pitch, that phenomenal gift about which much has been written. Her ability to identify pitches by name, without the slightest hesitation or tonal reference, had been demonstrated to this writer on numerous occasions. Despite this remarkable ability to identify pitches, and the fact that she received one of the highest singing accuracy scores, she was able to score perfect matches on only three of the fourteen pitch-matching tests.

Conclusions

According to analyses of the data from the eighty-one test subjects in this study, the most important factor of those considered in singing accuracy is vocal music experience. Although this may not entirely refute the opinion held by some music educators that certain persons simply cannot be taught to sing, the statistical evidence strongly suggests that singing ability is definitely related to singing experience. The data does not indicate that a subject sang well because of much vocal experience, neither does it show that he had an unusual amount of vocal experience because he sang well. No cause and effect relationship is implied.

The data does indicate the apparent existence for certain individuals of a point at which the inability to hear and to match pitches cannot be compensated for by any amount of vocal music experience, thereby enabling them to sing with acceptable intonation accuracy. It must be stated, however, that these individuals constitute a very small minority of about three per cent of the sample tested.

The second most important factor in singing accuracy, according to this study, is pitch-matching ability. Although the coefficient of correlation of raw scores is higher between vocal music experience and singing accuracy than between pitch-matching ability and singing accuracy, the difference is less than three percentage points for this particular sample. Therefore, the influence of pitch-matching ability on singing accuracy cannot be discounted.

The comparatively low correlation coefficient of raw scores of pitch-matching and instrumental music experience suggests, at least for this sample, that such instrumental music experience was mechanistic in nature. It would appear then that the training received in instrumental music had been primarily concerned with the mechanical aspects of correct fingering techniques for the instruments studied, and that inadequate attention had been given to the problems of intonation. Although an apparent indictment against teachers of instrumental music, this finding might also emphasize the complexities with which they must cope.

Recommendations

Definite pedagogical implications were suggested as this study progressed. Elaborate batteries of aptitude tests, intelligence tests, learning readiness tests, and achievement tests have been incorporated into the educational processes at all grade levels in recent years. When a child begins his schooling a file is begun in which complete records of his educational progress are kept. A cumulative record of the results of all the aforementioned tests is kept, including information of his family background and his personality traits and characteristics. Guidance counselors, trained in educational and psychological guidance techniques, utilize the information in the student's file to help him to acquire the best possible education for which he is equipped.

A valuable addition to the testing procedures already followed would be the inclusion of hearing tests for each child entering the first grade. This initial test of hearing acuity might be repeated periodically, and augmented with additional hearing tests until the student's "auditory profile" was compiled and made an integral part of his cumulative records.

The gradual development or advancement of a sensorineural impairment or loss often goes undetected by the victim for some time before he notices that his hearing is deteriorating. Teachers at all grade levels can attest to the difficulties encountered by students who are seemingly unaware of their own auditory deficiencies. The counseling programs already installed in school systems across the nation would be enhanced in value by the addition of factual information concerning the student's hearing ability.

Tests from which the "auditory profile" is compiled might well include those for hearing acuity throughout the normal tonal range of the human ear, roughly from 20 to 20,000 cycles per second. This test would disclose hearing defects referred to by Seashore as "tonal gaps" and "tonal islands," voids in the individual's hearing spectrum at or between certain frequencies.[21] Also included in the "auditory profile" might be information from tests of his pitch-matching ability, tests of ability to discriminate between pitch differences, and tests of his ability to discriminate between differences in tonal intensity.

The magnitude of the problem of hearing disorders among school-aged youngsters is underscored by J. Donald Harris of the C. W. Shilling Auditory Research Center, Groton, Connecticut.

> In any group of adolescents about 10% will probably have a loss of 20 dB or more in at least one ear at some usual audiometric frequency. About 3% will actually be acoustically handicapped; this may seem like a small percentage, but in absolute terms it comes to 30,000 unfortunate youngsters in a state with a million children of high school age.
> . . . About half of this loss is preventible, being due to largely correctible conditions of the middle ear and eustachian tube.[22]

The hypacusic youngster would unquestionably benefit from early detection of his hearing disorder. By a sustained program of retesting it might be determined if the hearing loss or deficiency is temporary or permanent, continuous or recurring, mild or acute. Likewise, early detection of such sensori-neural impairments could result in necessary medical attention while still correctible. Even those cases which cannot be medically corrected might be

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[21] Seashore, pp. 83-86.

[22] J. Donald Harris, "Research Frontiers in Audiology," *Modern Developments in Audiology*, ed. James Jerger (New York: Academic Press, 1963), p. 429.

alleviated by the fitting of binaural hearing aids of remarkable effeciency.

A youngster whose hearing is not compatible with participation in musical activities might be spared the innumerable frustrations and embarrassments such participation inevitably brings. Psychologists attest to benefits thus derived in the areas of psychological and personality development. However, since vocal music experience is indicated by the data of this study to be the most influential of the variables considered which affect singing accuracy, the recommendations for or against a child's participation in music activity should be made only on the basis of accurate and valid tests of his hearing.

Previously mentioned was the relatively low coefficient of correlation between instrumental music experience and singing accuracy. This does not reflect any particular discredit upon the quality of instrumental training received, but emphasizes the need for the beginning instrumentalist to be reminded that accurate intonation does not automatically result from following the fingering charts.

Many factors demand simultaneous attention from the beginning instrumentalist. In addition to the fundamental problems of music theory and sightreading presented by unfamiliar literature, the neophyte students of stringed instruments discover arm, hand, and instrument positions that seem awkward, and wrists and fingers that refuse to cooperate. Novice students of brass and wind instruments must simultaneously concentrate on instrument position, breath control, fingering, embouchure, and tonguing. Beginning piano and organ students are concerned with combinations of strength, suppleness, and agility of fingers and wrists, along with pedal technique and accuracy. Still, with all the problems relating to the mastery of technical facility which confront the instrumentalist, his teacher should encourage him to give continuing attention to accuracy of intonation and to the end product of melodic and harmonic beauty in the music he plays.

Suggestions for Further Research

Categorically, music educators are largely responsible for the dearth of definitive research conducted in contiguous areas related to problems inherent in their field. Although considerable investigation has been made of acoustical phenomena, otological abnormalities, and sound spectrum analysis, it remains for the music educator to apply the knowledge gained from these studies toward the solution of problems too long accommodated. Ordinarily the music educator has neither the available time, funds, and equipment, nor the technical preparation in physics, acoustics, electronics, statistics, and physiology necessaryfor such research. Nonetheless, continuing inquiry is needed in these peripheral areas to establish pedagogically sound procedures for the teaching of music and for the preparation and training of future generations of music educators.

In the area of instrumental music a study of pitch-duplication ability (intonation accuracy), coupled with tests for hearing acuity, pitch-matching ability, and pitch difference discrimination ability among instrumentalists might prove to be most enlightening. It might be concluded that certain instrumentalists cannot be expected to play with accurate intonation because of sensori-neural impairment. Indeed, a similar conclusion was drawn from this study of singers' intonation accuracy.

Another area in which further research is recommended concerns the influence of hearing via bone conduction. Anyone who has had his own speaking or singing voice recorded, then played back for his hearing, has been surprised at the difference in the two sounds. This difference is due to the influence of hearing via bone conduction. The recording presents a reasonably accurate duplication of his voice as it sounds to other people, with sound waves transmitted to his ear via air conduction, with only a negligible degree of bone-conducted stimulation. While singing, the singer hears his own voice through the combined, and virtually equal, influences of air conduction and bone conduction.

Consider the hypothetical, although quite realistic, possibility that a singer's left ear is quite reliable as to acuity and responses to frequency and intensity variations, as well as pitch perception as determined by conventional testing procedures utilizing electronically produced tone signals. Assume also that his right ear, subjected to the same testing procedures, scores poorly in response to minimal auditory stimuli (hearing acuity) and frequency variation-responsiveness. If the inaccuracy of his right ear is due to injury, or perhaps a birth defect or malformation of the tympanic membrane, is it not then possible that bone-conducted auditory stimuli of the semicircular canals, the vestibule, the cochlea, and the inner ear enclosed in the complexities of the labyrinth, might be more reliable than air-conducted stimuli? No less an authority than Békésy has stated that "the hearing of one's own voice by bone conduction is of the same order of magnitude as it is by air conduction."[23] Littler confirms that in clinical audiometry the relationship between bone conduction and air conduction thresholds is an aid in diagnosis and treatment.[24]

A singer with an otological condition such as the hypothetical one just described, ears that are not tuned together, might well hear a single tone played by an accompanying instrument as two separate pitches, resulting in his experiencing some degree of frustration and uncertainty as to which of the two pitches is the correct one to be sung.

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[23] Békésy, p. 187. [24] Littler, p. 209.

Research might conclude that air-conducted stimuli heard by his defective ear could be muted by a type of earplug which would enable the stimuli registered by the reliable ear to be greater in intensity. Such a predominance of sound heard by the more reliable of his two ears might supply accurate pitch references sufficient to make possible his singing with acceptable and greatly improved intonation accuracy.

Littler alludes to this possibility while referring to the phenomenon known as "obturation," or the occlusion effect. He mentions "an apparent increase in the efficiency of bone conduction when the meatus is blocked by a plug or closure in any way."[25]

A valuable contribution to the research literature of music education would be a study of the effect on singing accuracy of an accelerated curriculum of musical experiences. This would perhaps require the cooperation of a control group of youngsters whose preliminary tests indicate unusual difficulty in matching tones sung to them or pitches sounded on an instrument. Such a control group might be subjected to an intensive and carefully planned program of musical training over an extended period of time. The varied musical experiences of the control group might include a preponderance of singing and pitch-matching activities, to an extent considerably in excess of those exper-

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[25] Littler, p. 219.

ienced by other children of comparable age who are not so saturated with musical participation. Periodic comparisons of the control group with other children might yield significant information as to the pedagogical value of such remedial musical training.

Another area of investigation which could be of interest and value to the music educator is that of selective auditory sensitivity. The predictability of specific reactions in human behavior to predetermined stimuli is voluminously reported in literature of psychology. Writings in the field of psychiatry refer to the retentive capacity of the human mind as being comparable to recent and dramatic developments in elaborate data storage and retrieval systems. Psychologists tell us that the human brain is capable of suppressing, and sometimes completely ignoring, sensory signals while under particular emotional or stress conditions. Further research in this area conceivably might result in the conclusion that the brain may be trained or conditioned to ignore the auditory stimuli received from one ear while continuing to respond to similar auditory stimuli from the other ear.

A person whose hearing in one ear is defective, due to extensive diplacusis or to vast tonal gaps in his auditory spectrum because of injury or congenital defects, probably would have extreme difficulty singing with acceptable intonation accuracy. Should his other ear be reasonably reliable as to pitch difference determination and hearing acuity, his ability to sing with acceptable accuracy of intonation might be greatly improved if the auditory stimuli of the defective ear could be mentally disregarded and ignored while singing. However remote this possibility may appear to be, it is surely worthy of investigation.

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